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EVALUATION OF 90-DAY INHALATION TOXICITY OF PETROLEUM AND OIL SHALE JP-5 JET FUEL

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TECHNICAL REVIEW AND APPROVAL

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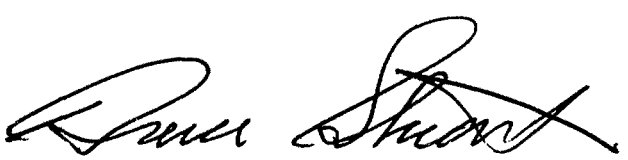
The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



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Subchronic 90-day inhalation studies were conducted to compare the toxicity of Petroleum and Oil Shale derived JP-5 jet fuel. Beagle dogs, Fischer 344 rats, and C57BL/6 mice were continuously exposed to JP-5 at concentrations of 150 mg/m^3 and 750 mg/m^3. Unexposed control groups were also maintained. All dogs and a portion of each rodent group were sacrificed and examined at exposure termination. Remaining rodents were held for observation up to 21 months postexposure. The most significant exposure related effect occurred in male rats, where JP-5 produced nephropathy characterized by hyaline droplets, necrosis, and intratubular casts. Accentuated tubular degeneration and medullary mineralization were noted in exposed rats held for long-term postexposure observation. Female rats were free of significant JP-5 related renal damage. Consistent with the pathologic changes in male rats exposed to 750 mg/m^3 were increased kidney weight and increased serum creatinine and BUN levels. Reduced body weight gains also occurred in male rats exposed to JP-5. No pathologic lesions were (continued)

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19. observed in dogs exposed to JP-5. Hepatocellular vacuolization and fatty change occurred in mice exposed to JP-5 from either source and in rats exposed to Shale JP-5. The results of this study suggest that there are no substantial differences between Petroleum and Shale JP-5.

PREFACE

This document constitutes the final report on the Evaluation of the 90-Day Inhalation Toxicity of Petroleum and Oil Shale JP-5 Jet Fuel. The research covered a period from July 1977 through July 1983 and was performed under Contract No. F33615-80-C-0512. M. K. Pinkerton and K. C. Back, Ph.D. served as technical contract monitors for the Air Force Aerospace Medical Research Laboratory.

This work was sponsered by the U.S. Navy under the direction of CDR L. J. Jenkins, MSC, USN, Ret.; LCDR M. J. Cowan, Jr., MSC, USN, Ret.; and Capt. D. E. Uddin, MSC, USN; and identified as Work Unit Number MF 58524001.0002.

J. D. MacEwen, Ph.D. served as the Laboratory Director for the THRU of the University of California, Irvine and as co-principal investigator with T. T. Crocker, M.D., Department of Community and Environmental Medicine. Acknowledgement is made to L. J. Jenkins, D. E. Uddin, C. D. Flemming, and R. K. Blasingame for their significant contributions and assistance in the preparation of this report.

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INTRODUCTION

Petroleum distillates have been used as large scale sources of energy for over one hundred years, and since the advent of the internal combustion engine, vast quantities of distillate fractions have been introduced into man's working environment. The development of jet engines as almost universal power plants for commercial and military aircraft has led to the use of a number of petroleum distillate fuels with special properties. These are less volatile than the gasoline fractions used in conventional internal combustion engines.

Despite long industrial and environmental experience with petroleum distillates, little investigative work was done on the toxicological characteristics of these fuels until Drinker et al. (1943) exposed groups of human volunteers to known concentrations of gasoline vapor. They found that for concentrations up to 0.03% (1060 mg/m^3) the major complaint was eye irritation. When the concentration reached 0.26% (9150 mg/m^3) symptoms appeared of mild exhilaration and muscular incoordination characteristic of moderate ethanol ingestion. At a concentration of 1.1% or 38,800 mg/m^3, the subjects were described as appearing intoxicated, most within 5 minutes.

As a result of these studies and industrial experience, the ACGIH assigned a TLV of 500 ppm or 1760 mg/m^3 to gasoline. Then in 1963, Elkins et al. pointed out that the relative concentration of benzene in air after evaporation of gasoline, either totally or partially, would be greater than its volume or weight concentration in the liquid phase, leading to the possibility that the Threshold Limit Value (TLV) of benzene at that time, 25 ppm, might be exceeded in a mixed fuel concentration below the gasoline TLV. In response, the ACGIH in 1967 changed its approach in favor of determining the TLV on the basis of the content of benzene, other aromatics, and additives in gasoline or petroleum distillates.

In 1973, the THRU undertook an 8-month study of JP-4 jet fuel under a 6 hour/day, 5 day/week exposure regimen (MacEwen and Vernot, 1974). In this experiment, the aim was to generate concentrations of JP-4 which contained 25 and 12.5 ppm of benzene and, as a positive control, 25 ppm benzene alone, which was the current TLV. Preliminary experiments indicated the required concentrations of JP-4 were 5 and 2.5 mg/L. As different containers of JP-4 were used, the benzene content changed slightly, and the concentrations of JP-4 vapor were changed to keep benzene concentrations constant.

Activity depression was noted during the initial 3 weeks of the study in dogs and monkeys exposed to benzene or JP-4 vapors. A statistically significant increase was noted in RBC fragility in female dogs between the 10th and 27th weeks of exposure to 5 mg/L. The increase was not seen in dogs exposed to the lower concentration of JP-4 or benzene. At sacrifice, immediately postexposure, the liver, spleen, and kidney weights of rats exposed to 5 mg/L JP-4 were significantly higher than controls, and there was a higher incidence of chronic murine bronchitis in the rats exposed to either concentration. The only exposure related pathologic lesions at one year postexposure were increased hemosiderin deposits in the spleens of rats exposed to both concentrations of JP-4 and benzene alone.

The jet fuel of interest in the present study is designated JP-5. JP-5 is less volatile than JP-4 and also contains less benzene. The Naval Medical Research Institute Toxicology Detachment (NMRI/TD) requested that the Toxic Hazards Research Unit conduct comparative toxicity tests with JP-5 derived from both conventional petroleum and oil shale. Oil shale represents one of the largest underdeveloped sources of fossil energy in the United States. It is estimated that the Green River formation in Colorado, Utah, and Wyoming contains 600 billion barrels of recoverable oil, an amount that exceeds the known world liquid petroleum supply (Weaver and Gibson, 1979). The military is participating in an interagency effort to produce and refine large quantities of crude oil shale into military specification fuels for subsequent evaluation.

As part of the overall evaluation of the oil shale fuels, it is desirable to assess the toxicity associated with typical use exposure. Data of this type allow for a comparison of the hazards of the oil shale and petroleum fuels and are valuable in establishing proper workplace procedures and controls. Since inhalation will be a prime route of exposure for personnel working with JP-5, inhalation exposures were conducted to compare the effects at expected worker exposure levels. A 90-day, continuous inhalation exposure period was chosen to simulate conditions where Naval personnel may be exposed during a cruise situation. While this type of exposure is less traditional than a 6 hour/day, 5 day/week regimen, it does create a maximum exposure situation and increases the probability of observing exposure related effects.

Because of the unavailabiltiy of the Shale JP-5 at the onset of this study it was impossible to conduct simultaneous tests. The Shale JP-5 sample did not become available for testing until two years after initiation of the Petroleum JP-5 exposures.

Despite this lengthy time period between the studies, care was taken to insure that the experiments were conducted in as similar a manner as possible.

METHODS

Test Material

JP-5 is a high flashpoint, kerosene-type aviation turbine fuel described in military specification MIL-T-5624K, (1 April 1976), and in Table 1. Petroleum JP-5 was obtained from the stock supply at Wright-Patterson Air Force Base. Shale JP-5 was refined by SOHIO from hydrotreated Paraho crude. The fuels were supplied to the THRU by NMRI/TD in clean 55-gallon drums.

TABLE 1. MILITARY SPECIFICATIONS: JP-5

Distillation Temperature (°C)	
Initial Boiling Point	--
10% Recovery	205°
End Point, Maximum Temperature	290°
Aromatics, Vol %, Maximum	25
Olefins, Vol %, Maximum	5
Sulfur, Total Weight, % Maximum	0.4
Sulfur, Mercaptan, Weight %	0.001
Hydrogen Content, Weight %	13.5
Freezing Point, °C, Maximum	-46°
Density, g/mL at 15°C, Minimum	0.788
Maximum	0.845
Flashpoint, °C, Minimum	60°

JP-5 Generation and Monitoring

The petroleum and oil shale studies were both conducted in the same manner. The basic design for the JP-5 generation system was adapted from the previous study on JP-4. Since JP-5 jet aircraft fuel is a multicomponent material with a wide boiling range, it was necessary to operate the animal exposure chambers from a single master generation system (Figure 1) to assure similar exposure. To reduce potential fire hazard, an overheat alarm with a fuel shut off capability was incorporated into the generation apparatus.

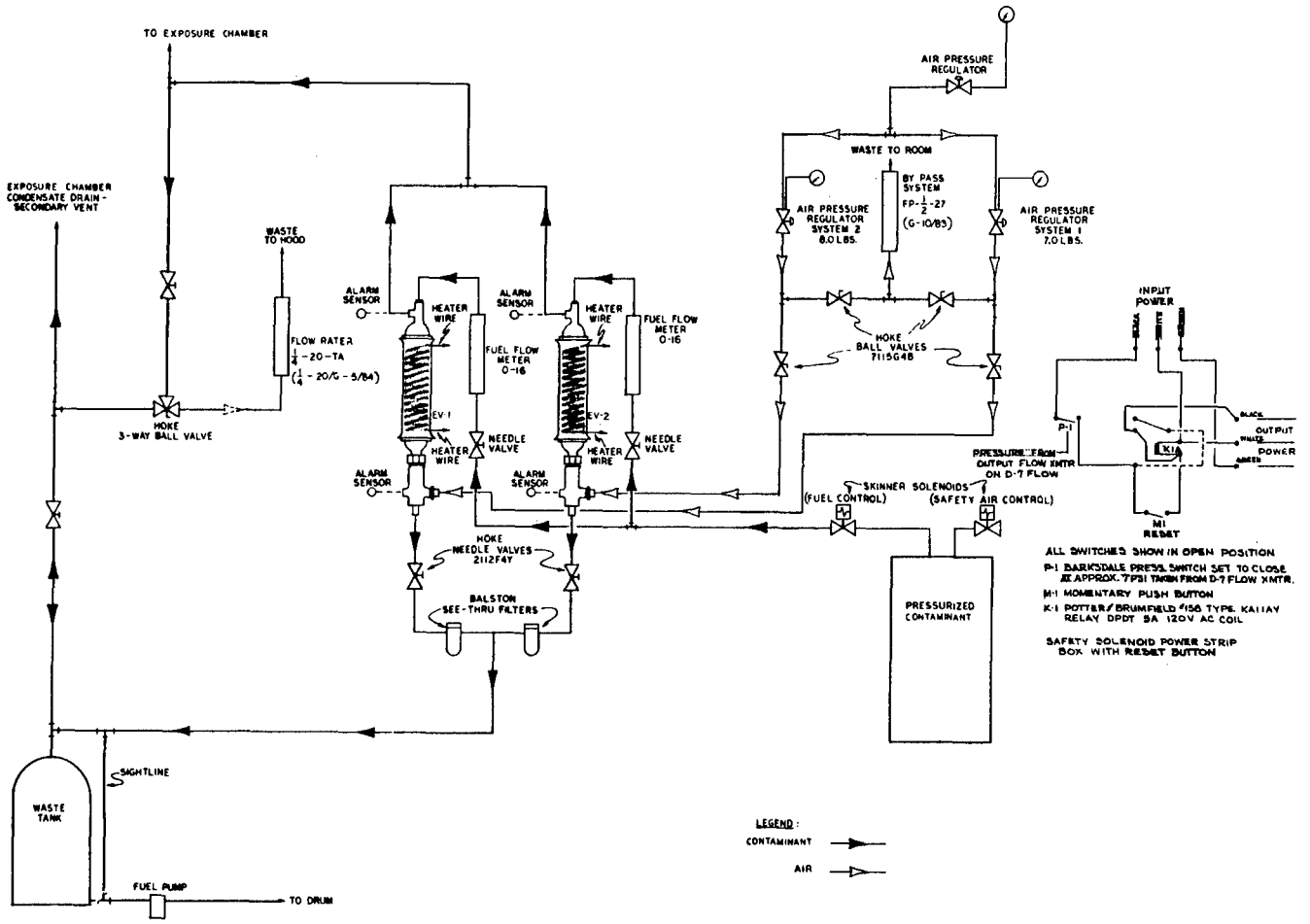

Figure 1. JP-5 contaminant introduction system.

Two identically operated solvent evaporator towers were required to generate sufficient fuel vapor for the assigned chamber concentrations. The central zone of the glass tower was a cylinder 13" long by 1-3/4" O.D. It had a 13-turn spiral 9" long impressed in the wall to hold a heating coil and lengthen the evaporation path. The top reduced to a "T" with a 1" O.D. right arm for vapor exhaust and a 1/4" O.D. connector for input fuel. The bottom reduced to a 1" O.D. glass connector. JP-5 was metered in the top of the two electrically heated evaporator towers. Air entered the tower at the side near the bottom while spent fuel was drained from the bottom. The hot fuel vapor/air mix was split in the approximate volume ratio of the high and low chamber concentrations and entered the respective chamber air streams. A double "T" of stainless steel tubing and pipe fittings allowed input air, spent fuel exit and temperature monitoring of the waste fuel. A valve downstream controlled air/spent fuel flow to reduce vapor loss from the bottom of the tower. The primary source of heat was a 1/4" O.D. close coiled Nichrome wire

(B & S-20 gallon, 1.1 Ω/inch, Wooge Manufacturing Company, Chicago, Illinois). The close coil length used on each solvent evaporator tower was approximately 72". It is rated at approximately 1000 watts using a 115 V source. Additional heat was added to the system by wrapping the metal fittings at the bottom of the tower with electrical heating tape. Both tower and base heat sources were controlled by using variable voltage transformers.

Rather large volumes (100-150 gallons) of fuel were necessarily present in the area adjoining the chambers for prolonged periods of time. Because the system had to operate unattended except for hourly operational checks continuously for over 100 days for each study, an overheat alarm/shutdown system shown in Figure 2 was incorporated. Four temperature probes, each capable of system shutdown, were placed at the most sensitive problem areas (fuel vapor/air mix leaving each tower and fuel draining from bottom of each tower). The temperature at each probe position was recorded hourly.

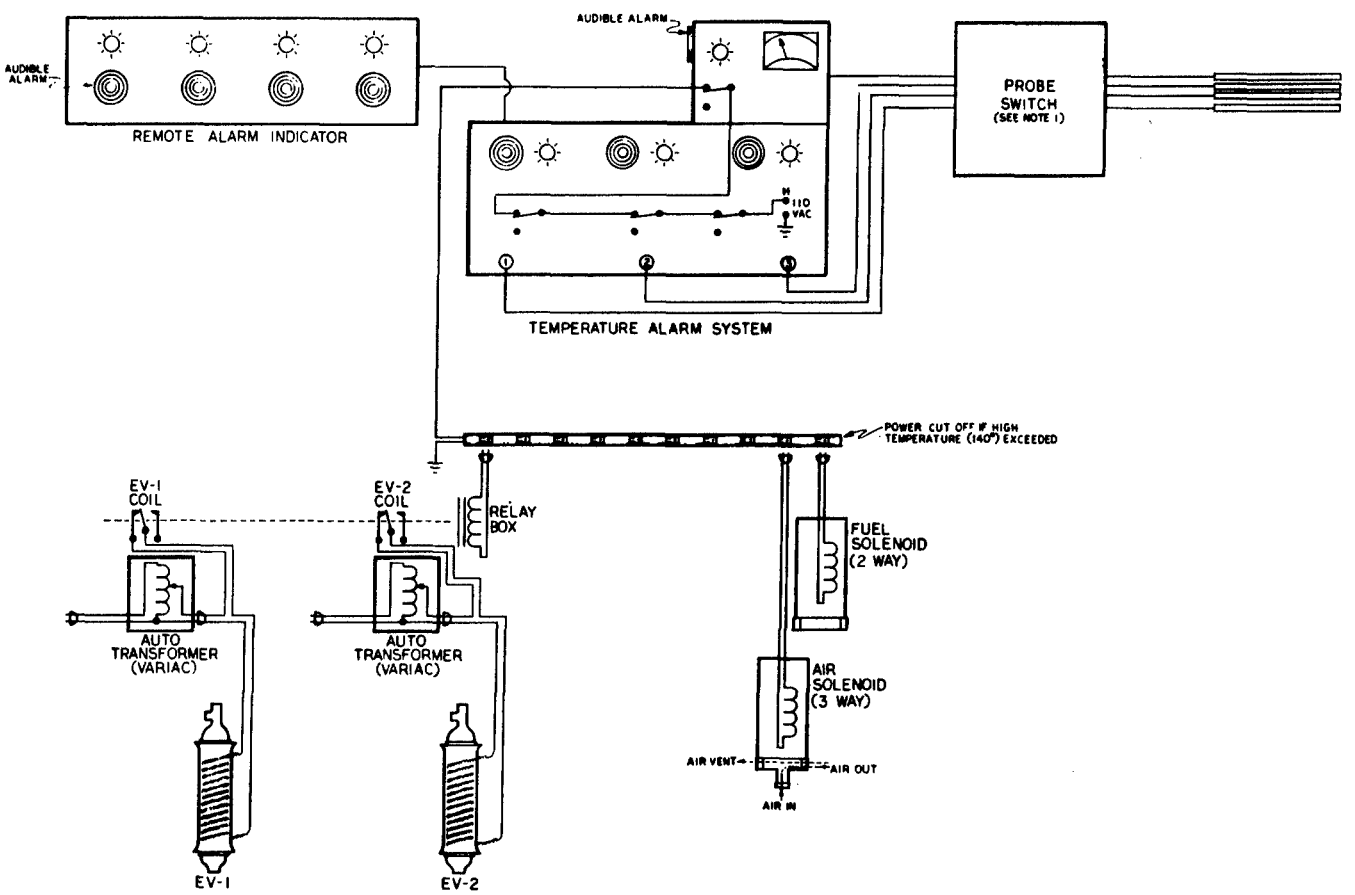

Figure 2. JP-5 contaminant introduction alarm system.

On shutdown, all heater power was turned off, fuel flow stopped and fuel pressure relieved and the fuel drums vented through the generation hood exhaust. In case of power failure, the whole system would shut down in the same manner. The temperature limit used was 120°F at the fuel vapor/air mix leaving the tower. Both upper and lower temperature sensor systems were set to trip off at 140°F.

The mass of hydrocarbon vaporized per unit time was dependent on the effective heat input while the vapor component concentration was affected by the ratio of components present in the fuel and the fuel flow rate. The system as operated had a fuel flow rate limit of about 15 mL/tower per minute.

A Beckman Model 400 hydrocarbon analyzer was used for mass analysis. Chamber concentrations were analyzed using a single analyzer by dilution of the higher JP-5 concentration chamber sample to a similar concentration as the low concentration using input chamber air for diluent and as the source of baseline air (Figure 3).

Since the hydrocarbon analyzer response was directly related to the total carbon content of the sample, standardization was

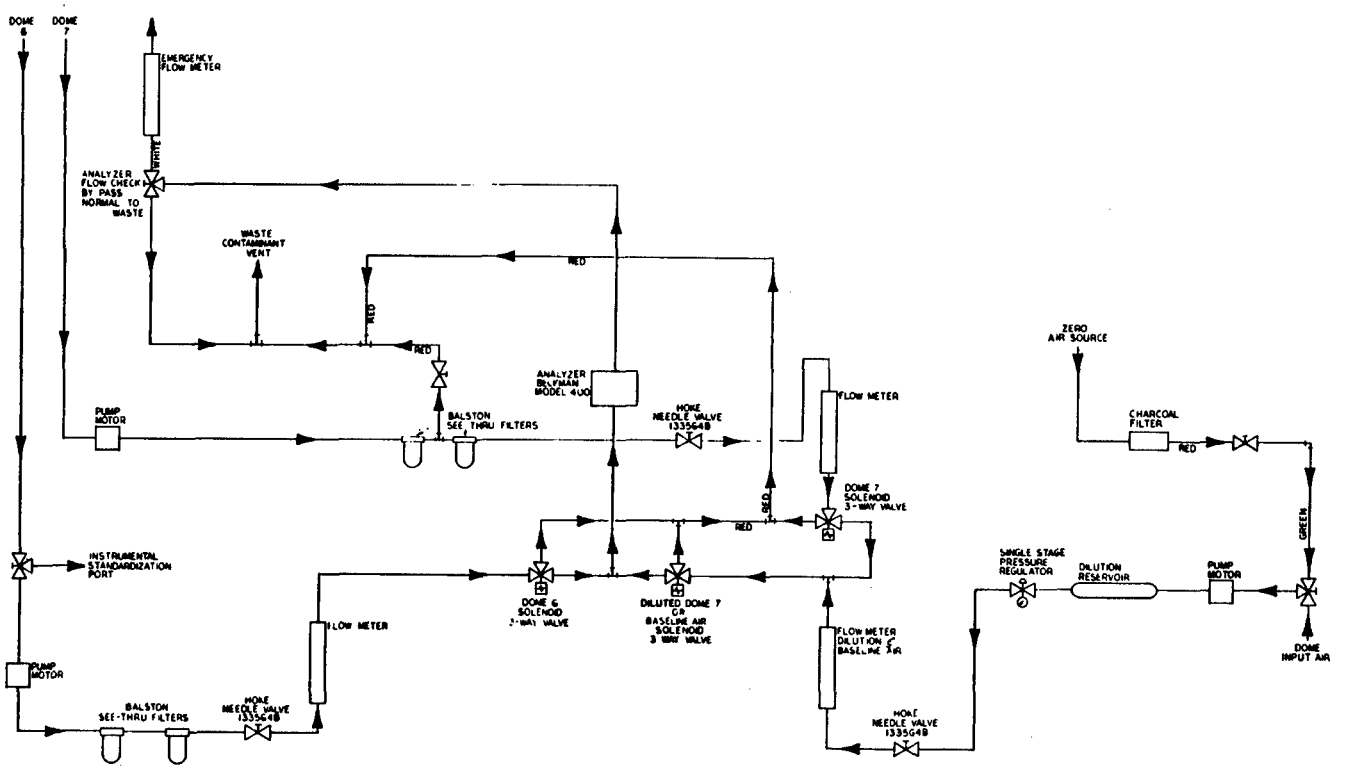

Figure 3. JP-5 sampling and analysis system.

possible using a reliable defined system. Instrument grade propane (99 + % as C_3), diluted in 100 L mylar bags, served as standards. Instrumental response was determined to be linear and stable for prolonged periods of time, provided the instrumental parameters were strictly maintained. Twenty-four hourly mean readings were used for daily concentration determinations.

In the Petroleum JP-5 study a Varian 1200 gas chromatograph (GC) equipped with a FID detector and a Spectra Physics Model I computing integrator was used for quality control analysis of each drum of fuel prior to use, analysis of spent fuel to monitor generation system operation, and chamber atmosphere fingerprint analysis. The GC was operated isothermally with the oven set at 40°C. Routine chromatographs were limited to peaks eluted in the first 20 minutes. The Shale JP-5 study employed a Varian 3700 GC equipped with a FID detector and a Spectra Physics Model I computing integrator. This system allowed for a more complete fuel analysis using a temperature program. Columns used for Petroleum or Shale JP-5 analysis were packed with either 10% SE 30 on Chromosorb W-AW or 10% SE 30 on Chromosorb W-HP.

Animals

Young, adult purebred beagle dogs were selected from a colony maintained by the Air Force at Wright-Patterson Air Force Base. Fischer 344 rats (9-11 weeks old) were purchased from Charles River Breeding Laboratories (Wilmington, Massachusetts). C57BL/6 mice (9-11 weeks old) were purchased from Jackson Laboratories (Bar Harbor, Maine). Test animals were gang-caged by species in stainless steel, wire-mesh cages during exposure. Animals had access to food (Purina, St. Louis, Missouri) and water ad libitum. All cage areas were cleaned daily during which time food remaining in the feeders was discarded and replaced with a fresh supply.

Exposure Conditions

Groups of dogs, rats, and mice (Table 2) were exposed via inhalation to Petroleum or Shale JP-5 vapor continuously for a period of 90 days. Exposures were conducted on a 24-hour basis and personnel servicing the chambers during the exposure were provided with respiratory protection and disposable protective clothing. Exposures were conducted in 25 m^3 inhalation chambers located at Wright-Patterson Air Force Base. Control groups were maintained in Bioclean, laminar air flow rooms in a separate facility. The airflow, pressure, relative humidity, and

TABLE 2. ANIMAL GROUPS AT EACH CONCENTRATION (CONTROL, 150 MG/M^3, 750 MG/M^3)

Contaminant	Animal	No. of Males	No. of Females
Petroleum JP-5	Beagle dogs	3	3
	Fischer 344 rats	75	75
	C57BL/6 mice	--	111[a]
Shale JP-5	Beagle dogs	3	3
	Fischer 344 rats	75	75
	C57BL/6 mice	--	150

[a] Reduced number of mice due to reinitiation of exposure.

temperature of each chamber were monitored and recorded hourly. Relative humidity was maintained at 50% ± 10 and the temperature at 22°C ± 2. Because of space limitations, male mice were not included in the exposure.

Upon termination of the 90-day exposure period, all of the dogs and one-third of the rodents were killed for detection of pathologic lesions caused by exposure. The remaining rodents were held for long-term postexposure observation. An interim sacrifice was conducted at 19 months postexposure, with a final sacrifice during the 24th month of the study.

All animals were carefully observed throughout the exposure and postexposure periods for signs of altered physical condition. Rats and dogs were weighed individually at biweekly intervals during exposure, and rats were weighed monthly during the post-exposure period. Mice were weighed monthly throughout the study, and the group mean weights were monitored. All animals that died or were killed were necropsied. The following tissues were taken for histopathologic examination: adrenals, anus, bladder, brain, colon, duodenum, esophagus, gallbladder, heart, ileum, kidneys, larynx, liver, lungs and bronchi, mammary gland, mandibular lymph node, mesenteric lymph node, nasal cavity, ovaries, pancreas, parathyroids, pituitary, prostate, salivary gland, sciatic nerve, seminal vesicles, skin, spleen, bone-sternebrae, vertebrae or femur (plus marrow), stomach, testes, thigh muscle, thymus, thyroids, trachea, and uterus. The liver, spleen, and kidneys of individual rats were weighed during necropsy at exposure termination and 19 months postexposure. Liver, spleen, and kidney weights of dogs in the Shale JP-5 study were also measured. Dog red blood cell osmotic fragility tests were conducted at exposure termination. Blood samples were drawn from fasted dogs biweekly

and from fasted rats at exposure termination and interim necropsy for hematology and clinical chemistry tests: hematocrit (HCT), hemoglobin (HGB), red blood cell (RBC) count, white blood cell (WBC) count, differential, total protein, albumin, alkaline phosphatase, bilirubin, blood urea nitrogen (BUN), calcium, creatinine, glucose, glutamic-oxaloacetic transaminase (SGOT), glutamic-pyruvic transaminase (SGPT), potassium, and sodium.

Data Analysis

Body weights, blood test results, and organ weights were analyzed by an independent t-test, and a Fisher exact test was used to analyze the incidence of histopathologic lesions (Zar, 1974).

RESULTS

Analytical

Initially, animal exposures to JP-5 vapors were intended to be based on air concentrations that would result in benzene concentrations equal to 10 ppm and 1 ppm. In preliminary tests of Petroleum JP-5 vapor generation in the exposure chambers, it was determined that even though military specifications for refining of JP-5 fuel permitted up to 25% aromatic hydrocarbon content, the measured benzene content was very low. The highest benzene concentrations we were able to achieve in the exposure chamber ranged from 0.5 ppm to 0.7 ppm. These levels were reached at a petroleum JP-5 vapor concentration of 1500 mg/m^3, which also was the highest stable concentration attainable.

Shortly after initiation, unexpected deaths occurred in the exposed mice exposed to 1500 mg/m^3 Petroleum JP-5. Seventy-five of the group of 150 mice were dead by the end of 6 exposure days. Dogs were lethargic and appeared to be sleeping more than normal. Oily deposits were noticeable on the fur of both species and, in addition, oil deposits were seen on the chamber windows. Examination of the daily records from the hydrocarbon analyzer showed no significant deviation from the desired concentration of 1500 mg/m^3 JP-5. This evidence suggested that generation of this concentration of Petroleum JP-5 was producing an aerosol which was lethal to mice after a few days exposure.

A Royco particle counter was used to obtain some estimate of the aerosol concentration and distribution in the JP-5 exposure chambers. The resulting data are shown in Table 3. Over

TABLE 3. COMPARISON OF AEROSOL COUNTS OF AIR IN JP-5 EXPOSURE CHAMBERS

Particle Diameter, μm	Particles Per Cubic Foot (150 mg/m^3 JP-5)	(1500 mg/m^3 JP-5)
0.5 - 0.7	272	2.1×10^5
0.7 - 1.4	100	1.5×10^5
1.4 - 3.0	75	1.3×10^5
3.0 - 5.0	12	4.4×10^3
5.0	11	1.3×10^3

the range of particle sizes examined, the 1500 mg/m^3 exposure had a much higher aerosol density than the 150 mg/m^3 exposure.

The rate of introduction of JP-5 into the 1500 mg/m^3 chamber was subsequently lowered to give a chamber concentration of 750 mg/m^3. After allowing time for equilibration, particle density was again measured with the results shown in Table 4. Also shown for comparison is the aerosol density found in laboratory air.

TABLE 4. COMPARISON OF AEROSOL COUNTS IN JP-5 EXPOSURE CHAMBERS AND IN LABORATORY AIR

Particle Diameter, μm	Particles Per Cubic Foot Laboratory Air	150 mg/m^3	750 mg/m^3
0.5 - 0.7	1400	740	3900
0.7 - 1.4	130	360	2300
1.4 - 3.0	41	310	900
3.0 - 5.0	7	200	33
5.0	4	3	11

Although no animals were in a chamber when measurements shown in Table 4 were made, it is obvious that the density of aerosol had been greatly reduced by decreasing the concentration of JP-5.

Based on the evidence that Petroleum JP-5 concentrations of 1500 mg/m^3 produced an aerosol exposure that was fatal to mice after several days, the initial study was terminated. New JP-5 subchronic exposure concentrations of 750 mg/m^3 and 150 mg/m^3 were selected. A new group of dogs was choosen from the original stock group for use in the Petroleum JP-5 exposure. The number

of mice in each group had to be reduced to avoid delays from ordering new animals. Spare mice from the original lot were available and were incorporated into the pool for redistribution of the exposure groups. Each Petroleum JP-5 study group then consisted of 111 mice instead of the original 150. At the time of the early termination, the rats had not yet entered the exposure chambers. They were therefore maintained until the Petroleum JP-5 study was restarted. Reduction of the concentration allowed the Petroleum JP-5 study to be conducted without further incident.

Exposure concentrations were well controlled throughout both studies. Table 5 shows the mean concentrations for the entire 90-day period. Also shown are the ranges of daily mean concentrations.

TABLE 5. SUMMARY OF JP-5 EXPOSURE CONCENTRATION INFORMATION

	150 mg/m^3 Target Concentration	750 mg/m^3 Target Concentration
Petroleum JP-5		
Mean (mg/m^3)	151	750
Range (mg/m^3)	148-157	716-796
Shale JP-5		
Mean (mg/m^3)	150	751
Range (mg/m^3)	147-155	735-769

Gas chromatographic analyses performed during the Petroleum JP-5 study were intended only to determine the benzene concentration. Use of this method showed a benzene concentration in the 150 mg/m^3 exposure chamber averaging about 0.1 ppm (range: 0.06 to 0.12 ppm). The 750 mg/m^3 chamber contained approximately 0.5 ppm (range: 0.33 to 0.57 ppm). The use of a single pass vapor generation system in this study resulted in the vaporization of about 8% of the total fuel mass. Because of the temperature limitations imposed on the generation towers there was a selective vaporization of the more volatile components of JP-5. The slightly different GC technique used in the Shale JP-5 study established that the majority of the constituents in the chamber were between C_{10} and C_{14}. This type of specific analysis was not conducted in the Petroleum JP-5 study.

Dogs

The growth of beagle dogs exposed to either Petroleum or Shale JP-5 was unaffected by 90 days of continuous exposure (Table 6), and no deaths resulted from exposure to either fuel.

TABLE 6. EFFECT OF JP-5 VAPOR EXPOSURE ON DOG BODY WEIGHT[a]

	Petroleum JP-5 Concentration (mg/m^3)		
Time (wk)	0	150	750
0	6.2 ± 0.8	6.2 ± 0.6	5.4 ± 0.2[b]
1	7.3 ± 0.4	7.4 ± 0.8	---
3/1[c]	7.8 ± 0.8	7.9 ± 0.9	6.9 ± 0.7
5/3	8.4 ± 0.9	8.2 ± 1.1	7.5 ± 0.9
7/5	8.8 ± 0.9	9.1 ± 1.2	8.2 ± 1.1
9/7	9.2 ± 1.0	10.0 ± 1.2	9.1 ± 1.3
11/9	10.0 ± 1.0	10.3 ± 1.4	9.3 ± 1.3
13/11	10.3 ± 1.0	10.7 ± 1.5	9.6 ± 1.3
-/13			9.9 ± 1.5

	Shale JP-5 Concentration (mg/m^3)		
Time (wk)	0	150	750
0	9.5 ± 1.1	9.8 ± 1.5	9.0 ± 1.7
2	9.8 ± 0.9	10.4 ± 1.2	10.4 ± 1.2
4	10.1 ± 0.8	10.8 ± 1.0	10.8 ± 1.4
6	10.5 ± 0.6	11.0 ± 1.2	11.2 ± 1.8
8	10.6 ± 1.0	11.3 ± 1.2	11.4 ± 1.8
10	10.5 ± 1.2	11.6 ± 1.2	11.5 ± 2.0
12	10.0 ± 1.3	11.6 ± 1.4	11.7 ± 2.2

[a] Mean ± SD, N = 6, weight in Kg.
[b] Significantly different from control value at $p < 0.05$.
[c] Reduction of the high level concentration resulted in a 2-week delay in exposure initiation at 750 mg/m^3. For statistical purposes (control vs 750 mg/m^3) values were compared on a real time basis.

Dogs exposed to Petroleum JP-5 for 90 days had increased red blood cell osmotic fragility when compared to controls (Figure 4). Although there was a slight shift in the curve toward increased fragility for the dogs exposed to 750 mg/m^3 Shale JP-5, the difference from the control values were not significant at $p < 0.05$. Slightly decreased red blood cell counts, hematocrit and

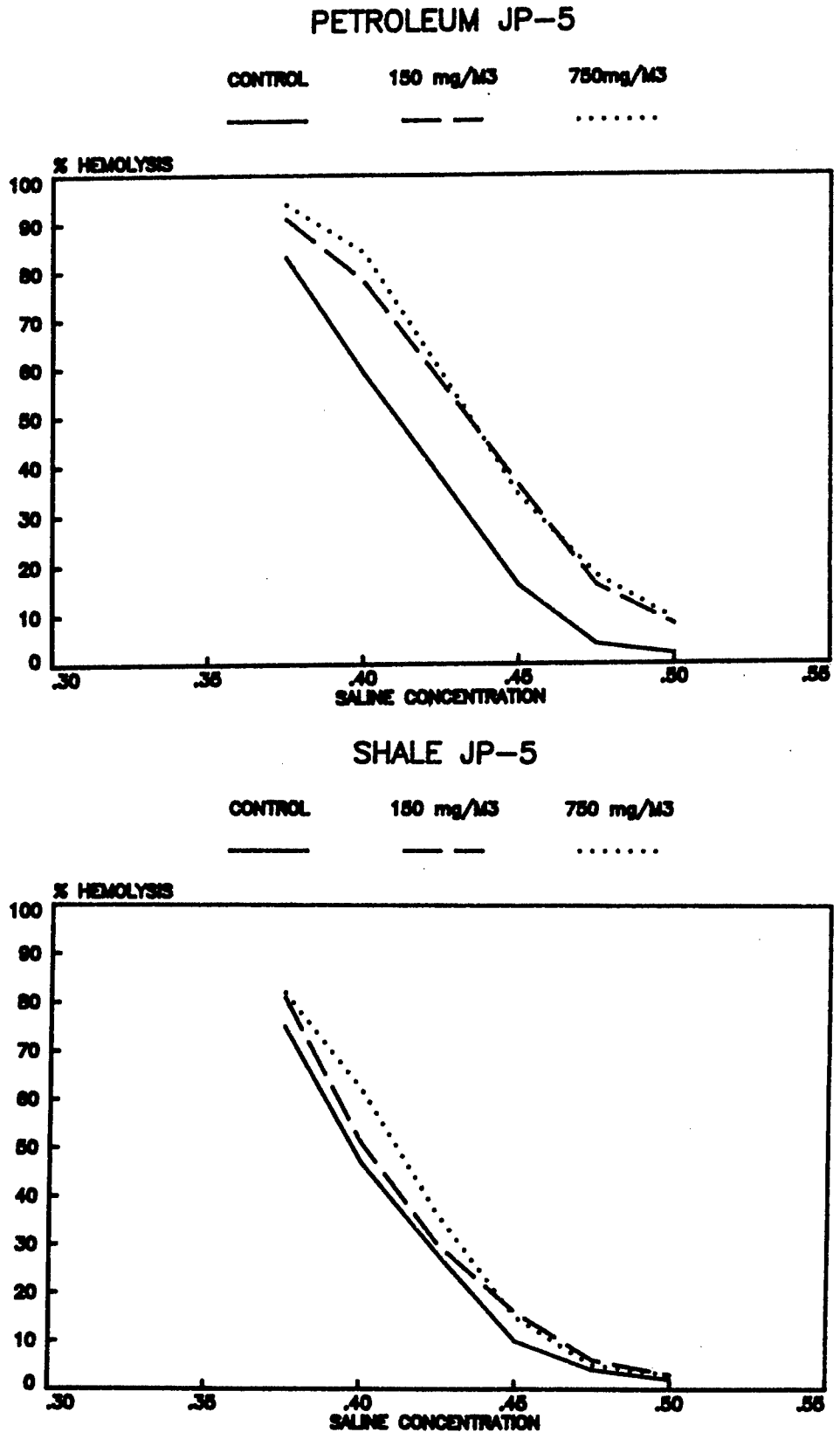

Figure 4. Effect of JP-5 vapor exposure on dog red blood cell osmotic fragility.

hemoglobin levels were seen in dogs exposed to either Petroleum or Shale JP-5 at 750 mg/m^3 when compared to respective controls (Table 7). Although this was a persistent trend, the differences were not always statistically significant at $p < 0.05$. All other hematalogic and clinical chemistry parameters measured were well within normal limits and failed to show any consistent exposure related effect.

TABLE 7. EFFECT OF JP-5 VAPOR EXPOSURE ON DOG RED BLOOD CELL COUNTS (RBC) HEMATOCRIT (HCT) AND HEMOGLOBIN (HGB)[a]

	Petroleum JP-5								
	RBC (x10^6 cells/mm^3)			HCT (%)			HGB (gm/dl)		
Time (wk)	Control	150 mg/m^3	750 mg/m^3	Control	150 mg/m^3	750 mg/m^3	Control	150 mg/m^3	750 mg/m^3
0	5.90 ± 0.47	5.79 ± 0.48	5.75 ± 0.44	41 ± 3	39 ± 3	41 ± 2	13.8 ± 0.9	13.5 ± 0.9	13.9 ± 0.6
1	6.21 ± 0.44	6.31 ± 0.58	---	40 ± 2	38 ± 2	---	13.9 ± 0.9	13.5 ± 0.8	---
3/1[b]	6.22 ± 0.80	6.27 ± 0.60	6.07 ± 0.45	41 ± 4	39 ± 3	41 ± 2	13.8 ± 1.3	13.3 ± 0.8	13.4 ± 0.6
5/3	6.96 ± 0.45	6.67 ± 0.57	6.05 ± 0.47[c]	44 ± 2	40 ± 3[d]	39 ± 2[c]	14.4 ± 0.8	13.9 ± 1.0	13.2 ± 0.7[d]
7/5	6.59 ± 0.32	6.14 ± 0.54	5.91 ± 0.45[d]	44 ± 3	41 ± 3	41 ± 2[d]	14.9 ± 0.7	14.2 ± 1.0	14.0 ± 0.6[d]
9/7	6.76 ± 0.38	6.76 ± 0.50	6.35 ± 0.30	45 ± 2	44 ± 3	43 ± 1	15.6 ± 0.7	14.9 ± 1.0	15.4 ± 0.6
11/9	6.75 ± 0.40	6.61 ± 0.47	6.12 ± 0.42[d]	46 ± 3	44 ± 2	43 ± 2	15.5 ± 0.7	14.9 ± 0.6	14.4 ± 0.8[d]
13/11	6.79 ± 0.44	7.06 ± 0.38	6.48 ± 0.28	46 ± 2	46 ± 3	45 ± 2	15.3 ± 0.7	15.6 ± 0.9	14.9 ± 0.6
	Shale JP-5								
	RBC (x10^6 cells/mm^3)			HCT (%)			HGB (gm/dl)		
Time (wk)	Control	150 mg/m^3	750 mg/m^3	Control	150 mg/m^3	750 mg/m^3	Control	150 mg/m^3	750 mg/m^3
0	7.13 ± 0.68	7.10 ± 0.54	7.28 ± 0.47	43 ± 5	43 ± 3	44 ± 2	14.4 ± 2.1	14.8 ± 1.4	14.7 ± 0.9
2	7.46 ± 0.79	7.15 ± 0.67	6.82 ± 0.78	44 ± 4	44 ± 4	41 ± 4	15.1 ± 1.8	14.9 ± 1.4	14.0 ± 1.6
4	7.39 ± 0.67	7.26 ± 0.46	6.73 ± 0.66	45 ± 4	45 ± 2	42 ± 3	15.0 ± 1.6	15.1 ± 0.6	14.1 ± 1.4
6	7.40 ± 0.63	7.58 ± 0.39	6.94 ± 0.73	45 ± 4	47 ± 1	42 ± 3	14.7 ± 1.3	16.4 ± 0.5[d]	14.4 ± 1.4
8	7.78 ± 0.57	7.70 ± 0.61	7.19 ± 0.63	47 ± 4	45 ± 2	44 ± 3	15.9 ± 1.4	15.6 ± 0.9	14.8 ± 1.0
10	7.70 ± 0.46	7.57 ± 0.12	6.95 ± 0.85	46 ± 3	47 ± 1	43 ± 4	15.8 ± 1.3	16.1 ± 0.7	14.8 ± 1.5
12	7.10 ± 0.60	6.86 ± 0.37	6.67 ± 0.79	45 ± 3	43 ± 2	44 ± 4	15.6 ± 1.1	15.6 ± 0.9	15.3 ± 1.4

[a] Mean ± SD, N = 6.
[b] Reduction of the high level concentration resulted in a 2-week delay in exposure initiation at 750 mg/m^3. For statistical purposes (control vs 750 mg/m^3) values were compared on a real time basis.
[c] Different from control, $p < 0.01$.
[d] Different from control, $p < 0.05$.

Increased liver weight was noted in dogs exposed to 750 mg/m^3 Shale JP-5 (Table 8). The increase was not evident in the dogs exposed to 150 mg/m^3 Shale JP-5. Organ weights were not measured on dogs exposed to Petroleum JP-5.

The majority of the lesions noted in the tissues of dogs exposed to either Petroleum or Shale JP-5 were not exposure related, changes occurring with equal distribution among all groups. The only exception was diffuse cloudy swelling of hepatocytes of dogs exposed to Petroleum JP-5. This occurred in all dogs exposed to 750 mg/m^3, two of the six dogs exposed to 150 mg/m^3, and none of the controls. Affected hepatocytes were moderately swollen, pale, and had a "foamy" cytoplasm. Transmission electron microscopic examination of a small number of these livers indicated this to be excessive glycogen accumulation.

TABLE 8. EFFECT OF 90 DAYS OF CONTINUOUS EXPOSURE TO SHALE JP-5 VAPOR ON DOG ORGAN WEIGHTS[a]

	Concentration mg/m^3		
	0	150	750
Body weight, kg	10.02 ± 1.32	11.56 ± 1.44	11.68 ± 2.18
Liver wt, g	291.9 ± 23.0	340.4 ± 37.7	424.9 ± 121.6[b]
Liver/100 g body wt	2.94 ± 0.31	2.95 ± 0.18	3.62 ± 0.65[b]
Spleen wt, g	71.6 ± 24.4	75.5 ± 30.2	79.2 ± 19.2
Spleen/100 g body wt	0.72 ± 0.24	0.66 ± 0.27	0.69 ± 0.24
Kidney wt, g	51.2 ± 6.8	51.5 ± 5.3	57.9 ± 9.7
Kidney/100 g body wt	0.51 ± 0.07	0.45 ± 0.04	0.50 ± 0.08

[a] Mean ± SD, N = 6.
[b] Different from control, $p < 0.05$.

Mice

Exposure of mice to Petroleum JP-5 produced a slightly shorter mean survival time when compared to their control group (Table 9). This effect was not seen in Shale JP-5 exposed mice. It was noted, however, that the control group in the petroleum study survived approximately 2.5 months longer than the control group in the shale study, and the survival time of the 750 mg/m^3 petroleum group was not inconsistent with any of the other groups.

Mouse body weights were unaffected by exposure to either Petroleum or Shale JP-5.

TABLE 9. SURVIVAL OF MICE EXPOSED TO JP-5

Treatment	Mean Survival Time (Month) ± SE	
	Petroleum JP-5	Shale JP-5
Control	21.5 ± 0.5	18.9 ± 0.6
150 mg/m^3	19.7 ± 0.6	18.4 ± 0.6
750 mg/m^3	17.3 ± 0.7[a]	18.1 ± 0.6

[a] Different from control, $p < 0.001$.

Hepatocellular fatty change and vacuolization were the only remarkable findings in mouse tissues examined at the completion of the 90-day exposure period (Table 10). Although most of the mice exposed to either Petroleum or Shale JP-5 displayed fatty livers after 90 days of exposure, the incidence was not dose related.

TABLE 10. INCIDENCE OF HEPATOCELLULAR FATTY CHANGE AND VACUOLIZATION OBSERVED IN FEMALE MICE AT TERMINATION OF 90 DAYS OF CONTINUOUS INHALATION EXPOSURE TO JP-5

	Concentration mg/m^3		
	0	150	750
Petroleum JP-5	8/37 (22)[a]	29/33 (88)[b]	23/34 (68)[b]
Shale JP-5	2/50 (4)	45/46 (98)[b]	42/49 (86)[b]

[a] Number observed/Number examined (%).
[b] Different from control, $p < 0.01$.

The major histopathologic changes noted in mice held for postexposure observation are shown in Table 11. The list has been abbreviated by excluding common lesions that appeared with low incidence. Chronic dermal inflammation and ulceration were common observations in all groups. However, ulceration did occur with a greater frequency in the mice exposed to 750 mg/m^3 JP-5. The appearance of granulocytic hyperplasia of the bone marrow was also common in all exposure groups and often corresponded with the presence of ulcerative dermatitis.

Lesions noted in the respiratory system of control and exposed mice included cytoplasmic hyaline change in the nose and inflammatory processes in the lung, including the combined diagnoses of acute and chronic inflammation, perivascular cuffing, lymphocytic infiltrates, interstitial inflammation, granulomatous inflammation and alveolar macrophages. These lesions were more frequently noted in the group of mice used in the Shale JP-5 study. Most importantly, primary lung tumors were not increased in mice exposed to either Petroleum or Shale JP-5 compared to respective controls.

Six hepatocellular adenomas were observed in the female mice exposed to 750 mg/m^3 Shale JP-5 while no primary liver cell tumors were observed in controls. Liver adenomas were not seen in mice exposed to Petroleum JP-5 at 750 mg/m^3, while three of

TABLE 11. HISTOPATHOLOGIC LESIONS[a] IN MICE HELD FOR POSTEXPOSURE OBSERVATION AFTER 90 DAYS OF CONTINUOUS INHALATION EXPOSURE TO JP-5

Tissue	Petroleum JP-5 Concentration (mg/m³) 0	150	750	Shale JP-5 Concentration (mg/m³) 0	150	750
Skin						
Ulcer	1/68 (1)	7/65 (11)[b]	13/66 (20)[c]	11/90 (12)	23/96 (24)	24/93 (26)[b]
Inflamation	18/68 (26)	15/65 (23)	8/66 (12)	3/90 (3)	1/96 (1)	0/93 (0)
Bone Marrow						
Granulocytic hyperplasia	26/65 (40)	26/61 (43)	23/65 (35)	35/86 (41)	26/93 (28)	38/94 (40)
Fibrosis	1/65 (2)	1/61 (2)	1/65 (2)	0/86 (0)	4/93 (4)	16/94 (17)[c]
Respiratory						
Nose - hyaline degeneration	19/68 (28)	8/66 (12)[b]	5/67 (7)[c]	65/93 (70)	53/97 (55)	62/96 (65)
Lung -						
inflammation	2/70 (3)	5/67 (7)	3/68 (4)	28/93 (30)	38/97 (39)	31/96 (32)
crystals	26/70 (37)	11/67 (16)	17/68 (25)	23/93 (25)	8/97 (8)	1/96 (1)
alveolar adenoma	5/70 (7)	1/67 (1)	1/68 (1)	1/93 (1)	2/97 (2)	2/96 (2)
alveolar carcinoma	0/70 (0)	1/67 (1)	0/68 (0)	2/93 (2)	0/97 (0)	1/96 (1)
Liver						
Clear cell focus	0/69 (0)	0/69 (0)	0/67 (0)	2/93 (2)	12/97 (12)[b]	4/95 (4)
Fatty Charge	41/69 (59)	28/69 (41)[b]	23/67 (34)[c]	57/93 (61)	56/97 (58)	66/95 (69)
Necrosis	2/69 (3)	2/69 (3)	0/67 (0)	8/93 (9)	5/97 (5)	5/95 (5)
Carcinoma	1/69 (1)	0/69 (0)	0/67 (0)	2/93 (2)	0/97 (0)	0/95 (0)
Adenoma	3/69 (4)	1/69 (1)	0/67 (0)	0/93 (0)	1/97 (1)	6/95 (6)[b]
Urinary						
Kidney - membrane glomerulonephritis	7/66 (11)	6/69 (9)	9/70 (13)	19/93 (20)	14/97 (14)	19/96 (20)
hyaline degeneration	0/66 (0)	5/69 (7)	1/70 (1)	6/93 (6)	0/97 (0)[b]	1/96 (1)
hydronephrosis	2/66 (3)	3/69 (4)	0/70 (0)	4/93 (4)	3/97 (3)	7/96 (7)
Reproductive & Endocrine						
Ovaries - cyst	11/63 (17)	13/57 (23)	7/57 (12)	17/94 (18)	17/93 (18)	13/96 (14)
Uterus - endometrial cyst	8/66 (12)	8/68 (12)	19/67 (28)[b]	48/91 (53)	58/97 (60)	31/93 (33)[b]
Pituitary - adenoma	28/54 (52)	24/45 (53)	21/51 (41)	49/82 (60)	40/85 (47)	38/76 (5)
- carcinoma	0/54 (0)	1/45 (2)	0/51 (0)	15/82 (18)	4/85 (5)[c]	2/76 (3)[c]
Thyroid -						
adenoma	1/68 (1)	5/61 (8)	3/64 (5)	9/91 (10)	11/96 (11)	6/90 (7)
carcinoma	0/68 (0)	1/61 (2)	0/64 (0)	1/91 (1)	0/96 (0)	0/90 (0)
papillary hyperplasia	38/68 (56)	27/61 (44)	34/64 (53)	71/91 (78)	62/96 (65)	70/90 (78)
Parathyroid - adenoma	0/33 (0)	0/25 (0)	0/16 (0)	0/52 (0)	1/69 (1)	0/39 (0)
- hyperplasia	0/33 (0)	0/25 (0)	0/16 (0)	1/52 (2)	0/69 (0)	0/39 (0)
Adrenal - carcinoma	0/67 (0)	0/64 (0)	0/67 (0)	1/95 (1)	0/96 (0)	0/96 (0)
- pheochomocytoma	0/67 (0)	0/64 (0)	0/67 (0)	1/95 (1)	0/96 (0)	0/96 (0)
Lymphoreticular						
Malignant lymphomas	8/70 (11)	14/69 (20)	9/71 (13)	40/91 (44)	30/94 (32)	25/95 (26)[b]
Digestive						
Stomach-ulcer	0/68 (0)	0/67 (0)	0/66 (0)	0/90 (0)	1/97 (1)	3/95 (3)
Gallbladder						
Hyaline degeneration	7/53 (13)	12/56 (21)	8/52 (15)	14/89 (57)	2/93 (2)[c]	24/86 (28)
Spleen						
Hematopoiesis	29/69 (42)	26/67 (39)	29/64 (45)	38/91 (42)	37/94 (39)	54/95 (57)[b]
Salivary Gland						
Perivascular cuffing	6/65 (9)	0/63 (0)[b]	9/64 (14)	37/84 (44)	37/94 (39)	53/90 (59)

[a] Number observed/Number examined (%).
[b] Different from control, $p < 0.05$.
[c] Different from control, $p < 0.01$.

the 71 respective control mice developed liver adenomas. Hepatocellular fatty change was commonly diagnosed in all groups of mice examined postexposure.

Lesions noted in the urinary system were generally unremarkable. All groups demonstrated a moderate incidence of membranous glomerulonephritis. Frequency of this change was slightly greater in the Shale JP-5 study. This was diagnosed when the glomerular capillary tufts appeared markedly thickened with homogenous, eosinophilic deposits. In some cases these deposits may have been amyloid fibrils while in other animals, immune complex deposition associated with murine oncornavirus infection was probably responsible. Tumors of the kidney were not seen in any of the JP-5 exposed mice.

Ovarian and uterine cystic changes were present with high frequency and variable distribution among all groups. Pituitary and thyroid follicular adenomas were also common in all groups. Adrenal tumors were noted only in two control mice in the Shale JP-5 study.

The other lesions noted with some frequency in mice included gallbladder hyaline degeneration, splenic hematopoiesis, malignant lymphomas and salivary gland perivascular cuffing. These are generally regarded as typical of aging, and the occasional increased incidence in the exposed groups compared to controls is considered to be incidental.

Rats

Exposure to either Petroleum or Shale JP-5 did not adversely affect survival of rats. The mean survival time for all groups in each study was approximately 22 months.

Depressed weight gains were noted in male rats exposed to either Petroleum or Shale JP-5 (Figure 5). The weights of male rats exposed to 750 mg/m^3 Petroleum JP-5 vapor were significantly ($p < 0.01$) less than unexposed control male rats through the exposure and postexposure phases of the study. Male rats exposed to 150 mg/m^3 Petroleum JP-5 vapor also weighed significantly ($p < 0.01$) less than unexposed control rats. However, this difference continued only through the 16th month of the study at which time the weights of this exposure group returned to the level of the unexposed control rats. Both groups of Shale JP-5 rats weighed significantly ($p < 0.05$) less than controls throughout the exposure and postexposure periods, with the weights generally following a dose response pattern. The body weights of female rats are shown in Figure 6. Exposure to Petroleum JP-5

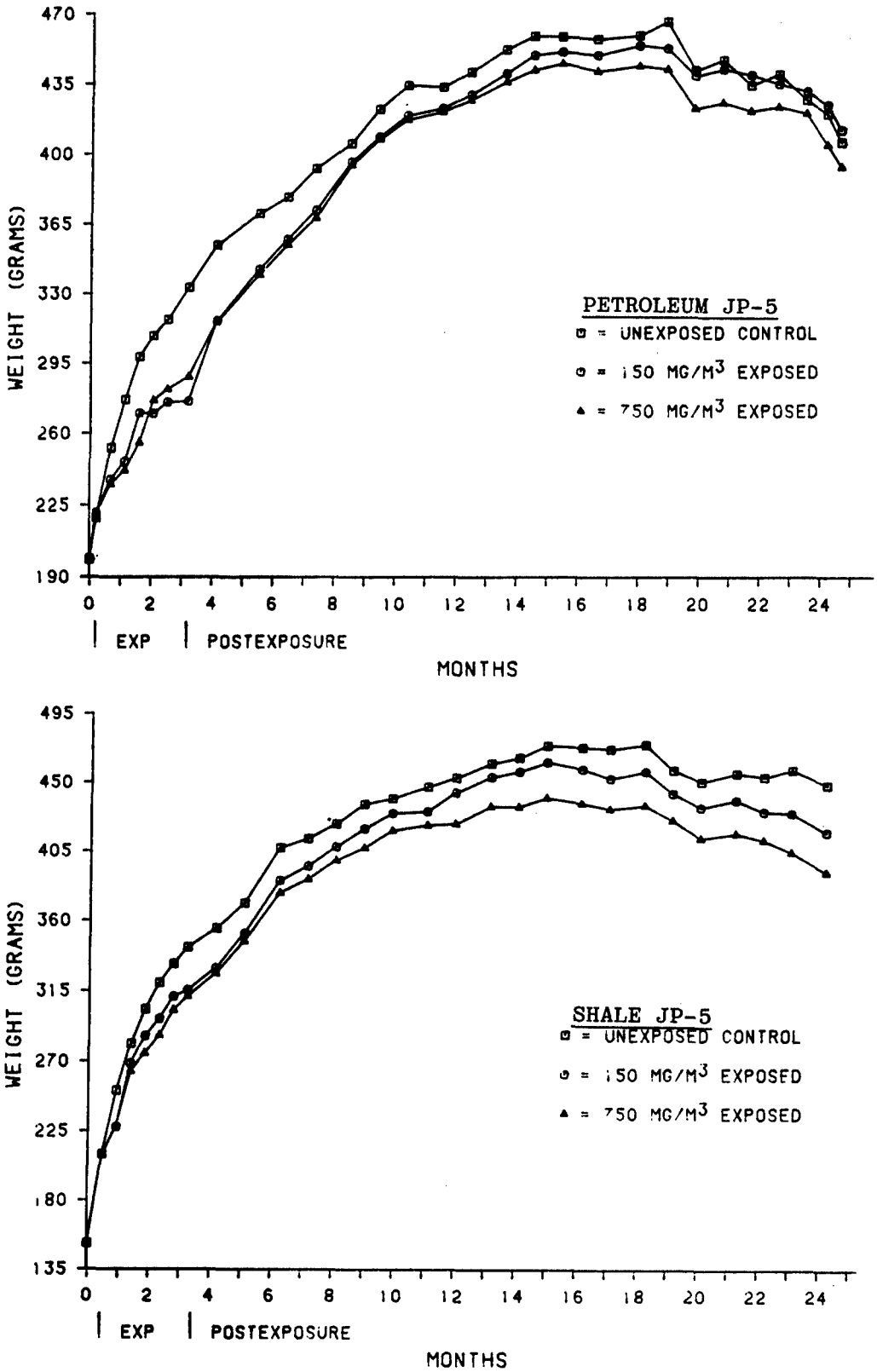

Figure 5. Effect of exposure to Petroleum JP-5 vapor (top curve) or Shale JP-5 vapor (bottom curve) on male rat body weight.

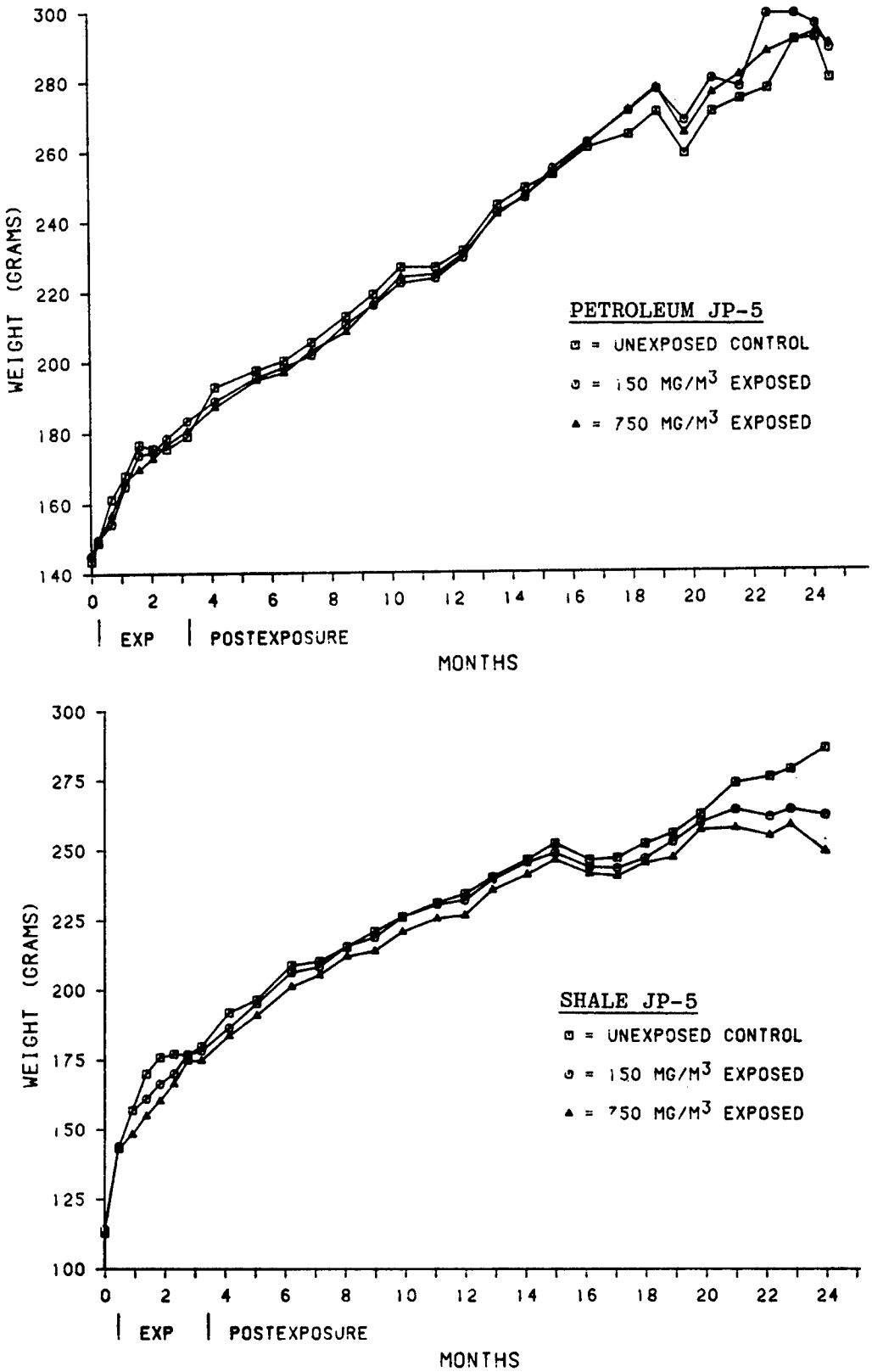

Figure 6. Effect of exposure to Petroleum JP-5 vapor (top curve) or Shale JP-5 vapor (bottom curve) on female rat body weight.

had no affect of female rat growth. Shale JP-5 at 750 mg/m^3 produced slight but statistically significant ($p < 0.05$) reduced growth through exposure and postexposure.

Male rat organ weights measured at the exposure and 19-month postexposure sacrifices are shown in Table 12. A slight but statistically significant increase in relative kidney weight was noted at both the exposure termination and postexposure examinations) in male rats exposed to either Petroleum or Shale JP-5 at 750 mg/m^3. This effect was not dose related as the kidneys of male rats exposed to JP-5 at the lower 150 mg/m^3 concentration generally weighed less than the respective control group rather than greater. At 19 months postexposure the spleens of three control male rats from the Petroleum JP-5 study were unusually large (42, 39, and 17 g). Other changes noted in JP-5 exposed male rat organ weights were sporadic and were considered incidental. Female rat organ weights are shown in Table 13. Changes in JP-5 exposed rat organ weights were generally without dose relationship and were therefore considered to be unrelated to exposure.

TABLE 12. EFFECT OF JP-5 VAPOR EXPOSURE ON MALE RAT ORGAN WEIGHT[a]

	Exposure Termination					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
Body weight (g)	328 ± 3	277 ± 3[b]	278 ± 3[b]	325 ± 3	303 ± 3[b]	294 ± 3[b]
Liver weight (g)	9.52 ± 0.19	7.02 ± 0.15[b]	7.92 ± 0.13[b]	8.77 ± 0.11	7.38 ± 0.11[b]	8.69 ± 0.10
Kidney weight (g)	2.18 ± 0.03	1.66 ± 0.02[b]	2.22 ± 0.03	2.23 ± 0.03	2.01 ± 0.03[b]	2.71 ± 0.03[b]
Spleen weight (g)	0.63 ± 0.01	0.48 ± 0.01[b]	0.48 ± 0.01[b]	0.58 ± 0.01	0.57 ± 0.01	0.58 ± 0.01
Liver % body	2.89 ± 0.05	2.53 ± 0.04[b]	2.84 ± 0.03	2.70 ± 0.02	2.44 ± 0.02[b]	2.95 ± 0.03[b]
Kidney % body	0.66 ± 0.01	0.59 ± 0.01[b]	0.71 ± 0.01[b]	0.69 ± 0.01	0.66 ± 0.01[c]	0.92 ± 0.01[b]
Spleen % body	0.19 ± 0.003	0.17 ± 0.003[b]	0.17 ± 0.003[b]	0.18 ± 0.003	0.19 ± 0.003	0.20 ± 0.004[b]
	19 months Postexposure					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0[d]	150[d]	750	0	150	750
Body weight (g)	420 ± 30	420 ± 30	398 ± 20[c]	437 ± 33	413 ± 24[b]	403 ± 24[b]
Liver weight (g)	12.37 ± 2.21	12.18 ± 1.14	12.54 ± 1.58	11.57 ± 1.93	11.07 ± 1.61	11.61 ± 1.49
Kidney weight (g)	2.84 ± 0.20	2.88 ± 0.15	3.04 ± 0.31[c]	2.89 ± 0.17	2.77 ± 0.37	2.90 ± 0.24
Spleen weight (g)	6.46 ± 12.55	1.61 ± 2.45	1.41 ± 0.70	1.50 ± 1.18	0.98 ± 0.21	1.56 ± 1.36
Liver % body	2.98 ± 0.70	2.90 ± 0.23	3.16 ± 0.43	2.66 ± 0.49	2.69 ± 0.47	2.89 ± 0.41
Kidney % body	0.68 ± 0.09	0.69 ± 0.04	0.77 ± 0.10[b]	0.66 ± 0.05	0.67 ± 0.11	0.72 ± 0.08[c]
Spleen % body	1.63 ± 3.17	0.39 ± 0.59	0.35 ± 0.18	0.35 ± 0.29	0.24 ± 0.05	0.39 ± 0.32

[a] Mean ± SD, N = 21 to 25 samples/group.
[b] Different from control, $p < 0.01$.
[c] Different from control, $p < 0.05$.
[d] N = 17.

TABLE 13. EFFECT OF JP-5 VAPOR EXPOSURE ON FEMALE RAT ORGAN WEIGHT[a]

	Exposure Termination					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
Body weight (g)	177 ± 7	181 ± 9[b]	172 ± 8	174 ± 7	168 ± 7[c]	158 ± 13[c]
Liver weight (g)	4.52 ± 0.38	4.16 ± 0.65[b]	4.26 ± 0.38[b]	4.44 ± 0.41[b]	4.18 ± 0.41[b]	4.17 ± 0.36[b]
Kidney weight (g)	1.24 ± 0.07	1.09 ± 0.10[c]	1.10 ± 0.08[c]	1.30 ± 0.08	1.20 ± 0.11[c]	1.23 ± 0.09[b]
Spleen weight (g)	0.41 ± 0.04	0.37 ± 0.05[c]	0.35 ± 0.05[c]	0.41 ± 0.05	0.39 ± 0.06	0.41 ± 0.06
Liver % body	2.56 ± 0.20	2.29 ± 0.30[c]	2.47 ± 0.19	2.55 ± 0.18	2.48 ± 0.23	2.66 ± 0.13[b]
Kidney % body	0.70 ± 0.04	0.60 ± 0.05[c]	0.64 ± 0.05[c]	0.75 ± 0.03	0.72 ± 0.06[b]	0.79 ± 0.08[b]
Spleen % body	0.23 ± 0.03	0.21 ± 0.03[c]	0.20 ± 0.03[c]	0.23 ± 0.03	0.23 ± 0.04	0.26 ± 0.03[c]
	19 Months Postexposure					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0[d]	150	750	0	150	750
Body weight (g)	268 ± 27	270 ± 22	273 ± 21	268 ± 17	252 ± 20	246 ± 19[c]
Liver weight (g)	6.79 ± 0.65	6.77 ± 0.87	6.76 ± 0.63	6.83 ± 0.63	6.58 ± 0.66	6.20 ± 0.65[c]
Kidney weight (g)	1.79 ± 0.13	1.78 ± 0.18	1.70 ± 0.34	1.89 ± 0.15	1.77 ± 0.10[c]	1.74 ± 0.13[c]
Spleen weight (g)	0.78 ± 0.48	0.53 ± 0.17	0.70 ± 0.40	0.54 ± 0.14	0.51 ± 0.05	0.57 ± 0.37
Liver % body	2.54 ± 0.21	2.51 ± 0.23	2.48 ± 0.21	2.55 ± 0.25	2.61 ± 0.16	2.55 ± 0.17
Kidney % body	0.67 ± 0.06	0.66 ± 0.05	0.63 ± 0.13	0.71 ± 0.06	0.70 ± 0.04	0.71 ± 0.04
Spleen % body	0.29 ± 0.17	0.20 ± 0.06	0.26 ± 0.15	0.20 ± 0.05	0.20 ± 0.03	0.23 ± 0.16

[a] Mean ± SD, N = 18 to 25 samples/group.
[b] Different from control, $p < 0.05$.
[c] Different from control, $p < 0.01$.
[d] N = 13.

Male rat hematology, BUN, and creatinine values measured during the study are shown in Table 14. Although all of the values determined at exposure termination were within normal variation for this species, there were some trends that were consistent with those mentioned previously for dog blood examinations. Slight but statistically significant ($p < 0.01$) reductions in red blood cell counts, hematocrit and hemoglobin levels were noted in JP-5 exposed male rats examined at exposure termination. BUN levels were also increased at that time in male rats exposed at the 750 mg/m^3 JP-5 level. Examination at 19 months did not indicate consistent reductions in erythrocyte parameters. The three male control rats from the Petroleum JP-5 study that had abnormally large spleens had WBC counts in excess of 48,000 $cell/m^3$. In these rats 80-90% of the WBC's were leukemic mononuclear cells. Blood values from these rats were excluded from statistical comparison. WBC abnormalities of this type were not found in Petroleum JP-5 exposed male rats nor in male rats from the Shale JP-5 study. Although BUN levels for the 750 mg/m^3 JP-5 exposure groups were greater than controls at 19 months postexposure, they were not statistically significant. Although occasional differences were noted between control and exposed female rat blood values, generally the female rats did not exhibit trends similar to the male rats (Table 15). Other blood parameters measured in male and female rats during the study were within normal species variation, and any differences between control and test groups were considered to be unrelated to exposure.

TABLE 14. EFFECT OF JP-5 VAPOR EXPOSURE ON MALE RAT BLOOD[a]

	Exposure Termination					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
RBC (x 10^6 cells/mm^3)	8.78 ± 0.37	8.43 ± 0.39[b]	8.41 ± 0.54[b]	9.84 ± 0.30	9.61 ± 0.39[c]	9.06 ± 0.37[b]
WBC (x 10^3 cells/mm^3)	5.4 ± 1.5	5.1 ± 0.6	5.4 ± 0.9	6.3 ± 1.0	6.5 ± 1.1	6.8 ± 1.0
HCT (%)	46 ± 2	45 ± 1[c]	42 ± 1[c]	49 ± 1	47 ± 2[c]	44 ± 1[c]
HGB (gm/dl)	15.3 ± 0.5	15.3 ± 0.4	14.7 ± 0.4[b]	16.3 ± 0.7	15.9 ± 0.8	15.0 ± 0.8[b]
BUN (mg/dl)	14.9 ± 2.2	17.0 ± 1.9[b]	18.5 ± 2.7[b]	17.8 ± 1.1	17.4 ± 1.6	20.3 ± 2.6[b]
Creatinine (mg/dl)	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1[b]	0.7 ± 0.1	0.7 ± 0.1	0.8 ± 0.1[b]
	19 Months Postexposure					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
RBC (x 10^6 cells/mm^3)	8.69 ± 0.63	8.51 ± 0.93	7.85 ± 1.32[c]	8.09 ± 1.45	8.12 ± 1.59	8.23 ± 1.81
WBC (x 10^3 cells/mm^3)	6.9 ± 3.0	7.2 ± 1.4	7.7 ± 2.1	5.1 ± 1.3	5.9 ± 1.1[c]	5.9 ± 1.1[c]
HCT (%)	51 ± 5	51 ± 6	51 ± 7	50 ± 8	51 ± 6	49 ± 7
HGB (gm/dl)	16.2 ± 1.5	16.7 ± 1.7	16.5 ± 1.8	16.9 ± 2.6	17.1 ± 2.2	16.2 ± 2.5
BUN (mg/dl)	16.6 ± 2.7	17.6 ± 3.7	18.7 ± 4.5	17.3 ± 2.3	19.9 ± 9.0	20.7 ± 6.4
Creatinine (mg/dl)	0.6 ± 0.1	0.6 ± 0.2	0.8 ± 0.1[c]	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.2

[a] Mean ± SD, N = 10 to 25 samples/group.
[b] Different from control, $p < 0.01$.
[c] Different from control, $p < 0.05$.

TABLE 15. EFFECT OF JP-5 VAPOR EXPOSURE ON FEMALE RAT BLOOD[a]

	Exposure Termination					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
RBC (x 10^6 cells/mm^3)	7.66 ± 0.26	7.91 ± 0.30[b]	8.05 ± 1 0.42[b]	8.76 ± 0.63	8.62 ± 0.68	8.46 ± 0.44
WBC (x 10^3 cells/mm^3)	4.1 ± 1.0	5.3 ± 0.9[b]	5.1 ± 1.0[b]	5.7 ± 1.0	5.2 ± 1.5	4.7 ± 1.4[b]
HCT (%)	42 ± 1	42 ± 1	42 ± 1	46 ± 1	45 ± 2[c]	44 ± 2[c]
HGB (gm/dl)	14.0 ± 0.3	14.5 ± 0.3[b]	14.3 ± 0.4[c]	14.8 ± 0.5	14.6 ± 0.6	14.2 ± 0.8[b]
BUN (mg/dl)	15.9 ± 1.6	19.4 ± 2.3[b]	19.6 ± 2.8[b]	22.2 ± 3.3	15.1 ± 1.5[b]	19.0 ± 4.4[c]
Creatinine (mg/dl)	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1[c]	0.6 ± 0.1	0.7 ± 0.1	0.7 ± 0.1
	19 Months Postexposure					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
RBC (x 10^6 cells/mm^3)	7.87 ± 0.91	8.47 ± 0.87[c]	8.79 ± 0.56[b]	7.18 ± 0.92	7.48 ± 0.63	7.29 ± 0.56
WBC (x 10^3 cells/mm^3)	5.4 ± 1.9	4.4 ± 1.4	4.4 ± 1.6	3.2 ± 1.0	3.3 ± 0.8	3.5 ± 1.0
HCT (%)	44 ± 2	45 ± 2	45 ± 2	43 ± 4	42 ± 23	43 ± 3
HGB (gm/dl)	14.7 ± 1.2	15.0 ± 0.7	14.9 ± 0.6	14.9 ± 1.2	14.5 ± 0.6	14.9 ± 1.0
BUN (mg/dl)	15.0 ± 1.3[d]	15.5 ± 1.1	15.5 ± 1.8	16.2 ± 2.3	15.1 ± 2.6	15.1 ± 2.4
Creatinine (mg/dl)	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.1[c]	0.5 ± 0.1	0.4 ± 0.1	0.4 ± 0.1

[a] Mean ± SD, N = 10 to 25 samples/group.
[b] Different from control, $p < 0.01$.
[c] Different from control, $p < 0.05$.
[d] N = 5.

Exposure of rats to Shale JP-5 resulted in mild hepatocellular vacuolization (fatty change) (Table 16). This effect was not dose-related in female rats and was absent in rats exposed to Petroleum JP-5. Mild nasal inflammatory changes occurred in Shale JP-5 exposed rats. The incidence was not dose-related. Petroleum JP-5 exposed rats were free of this lesion.

TABLE 16. HISTOPATHOLOGIC LESIONS IN RATS OBSERVED AT TERMINATION OF 90 DAYS OF CONTINUOUS INHALATION EXPOSURE TO JP-5

	Male Rats					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
Liver						
Vacuolization	1/25 (4)[a]	0/25 (0)	0/25 (0)	0/25 (0)	0/25 (0)	7/25 (28)[b]
Respiratory						
Nasal inflammation	0/25 (0)	0/25 (0)	0/25 (0)	0/25 (0)	21/25 (84)[b]	12/25 (48)[b]
Kidney						
Necrosis	0/25 (0)	22/25 (88)[b]	25/25 (100)[b]	0/25 (0)	24/25 (96)[b]	25/25 (100)[b]
	Female Rats					
	Petroleum JP-5 Concentration (mg/m^3)			Shale JP-5 Concentration (mg/m^3)		
	0	150	750	0	150	750
Liver						
Vacuolization	1/28 (4)	0/25 (0)	0/25 (0)	0/25 (0)	12/25 (48)[b]	9/25 (36)[b]
Respiratory						
Nasal inflammation	0/28 (0)	0/25 (0)	0/25 (0)	2/25 (8)	14/25 (56)[b]	10/25 (40)[b]
Kidney						
Necrosis	0/28 (0)	0/25 (0)	0/25 (0)	0/25 (0)	0/25 (0)	0/25 (0)

[a] Number observed/Number examined (%).
[b] Different from control, $p < 0.01$.

The most notable and obviously dose-dependent lesions found in rats were restricted to the kidneys of male subjects. Male rats examined immediately following exposure to either Petroleum or Shale JP-5 exhibited moderate to marked cytoplasmic hyaline droplets in proximal tubular epithelium followed by necrosis and exfoliation of tubular cells. Hyaline droplets were regarded as microscopically visible aggregates of protein. Their presence in the tubular epithelium suggested that cells were unable to efficiently transport resorbed protein from glomerular filtrate to the capillary blood. Subsequently, tubular segments near the corticomedullary junction were plugged and dilated with casts of necrotic cell debris. Affected segments corresponded with the

juncture of the pars recta of the proximal tubule and the descending limb of Henle's loop. Incidence of necrosis in all exposed groups was at or near 100%. However, a clear dose response was seen in severity with minimal renal changes at 150 mg/m^3, while lesions found at 750 mg/m^3 were characterized as moderate. Glomeruli were morphologically unremarkable by both electron and light microscopic analysis.

Results of microscopic examination of tissues collected from male rats maintained for postexposure observation are shown in Table 17. Only the lesions occurring with some frequency are shown. As at exposure termination, the most striking lesions associated with JP-5 exposure were found in the kidneys of male rats. These changes included focal diffuse papillary hyperplasia of the pelvic urothelium over the surface of the renal papillus, moderate to severe deposits of mineralized debris in medullary tubules (probably at the loop of Henle), and tubular degeneration. Hyperplastic areas along the pelvic urothelium were thought to result from mechanical irritation by mineralized debris shed from the tubules into the pelvis during exposure, combined with panrenal hypertrophy associated with chronic progressive nephropathy (CPN). In turn the mineralized tubular deposits probably represent calcium impregnated debris resulting from tubular necrosis occurring during the exposure phase of the experiment. Tubular degenerative changes were entirely compatible with CPN which is common in aged Fischer 344 rats. The severity of CPN, however, did appear to be slightly greater in the JP-5 exposed male rats. No kidney tumors were found in JP-5 exposed male rats.

Select tumors and tissue changes were recorded with increased frequency in several endocrine organs in exposed male rats. Although a slight increase in the incidence of pituitary tumors was found, these were not considered to be highly significant. Pituitary tumors are extremely common in aged Fischer 344 rats. Tumors of the thyroid parafollicular cells may be related to prolonged $Ca:PO_4$ imbalances secondary to severe nephropathy. Other endocrine lesions recorded in the studies were considered to be common findings in aged rats, and their apparent increase in some exposed groups is probably incidental. Neither Petroleum nor Shale JP-5 produced any increase in liver or lung tumors.

Results of the microscopic examination of the tissues collected from female rats at the end of 19 months postexposure observation are shown in Table 18. As at exposure termination sacrifice, the female rats failed to display any indication of JP-5 induced renal damage.

TABLE 17. HISTOPATHOLOGIC LESIONS[a] IN MALE RATS HELD FOR POSTEXPOSURE OBSERVATION AFTER 90 DAYS OF CONTINUOUS INHALATION EXPOSURE TO JP-5

Tissue	Petroleum JP-5 Concentration (mg/m^3) 0	Petroleum JP-5 Concentration (mg/m^3) 150	Petroleum JP-5 Concentration (mg/m^3) 750	Shale JP-5 Concentration (mg/m^3) 0	Shale JP-5 Concentration (mg/m^3) 150	Shale JP-5 Concentration (mg/m^3) 750
Skin						
Mammary gland -						
hyperplasia/dilatation	4/18 (14)	7/19 (24)	6/32 (19)	6/34 (18)	12/34 (35)	12/37 (32)
adenocarcinoma	0/28 (0)	0/29 (0)	0/32 (0)	0/34 (0)	1/34 (3)	0/37 (0)
fibroadenoma	1/28 (4)	2/29 (7)	1/32 (3)	0/34 (0)	0/34 (0)	2/37 (5)
Cardiovascular						
Myocardial fibrosis	6/49 (12)	2/50 (4)	4/49 (8)	23/50 (46)	15/49 (31)	21/50 (42)
Pulmonary artery mineralization	29/50 (58)	25/50 (50)	30/50 (60)	24/50 (48)	25/50 (50)	27/50 (54)
Respiratory						
Nose - inflammation	4/49 (8)	4/49 (8)	8/49 (16)	12/50 (24)	8/50 (16)	6/48 (13)
Lung -						
alveolar adenoma	0/50 (0)	0/50 (0)	0/50 (0)	0/50 (0)	1/50 (2)	0/50 (0)
alveolar carcinoma	0/50 (0)	1/50 (2)	2/50 (4)	1/50 (2)	0/50 (0)	0/50 (0)
Liver						
Focal cell change	23/50 (46)	29/50 (58)	32/49 (65)	38/50 (76)	38/50 (76)	41/50 (82)
Neoplastic nodule	1/50 (2)	1/50 (2)	0/49 (0)	2/50 (4)	0/50 (0)	4/50 (8)
Carcinoma	0/50 (0)	0/50 (0)	0/49 (0)	0/50 (0)	1/50 (2)	0/50 (0)
Adenoma	1/50 (2)	2/50 (4)	0/49 (0)	0/50 (0)	0/50 (0)	0/50 (0)
Urinary						
Kidney -						
tubular degeneration	42/50 (84)	46/48 (96)	48/50 (96)	34/50 (68)	44/49 (90)[b]	48/49 (98)[c]
papillary hyperplasia	0/50 (0)	2/48 (4)	23/50 (46)[c]	0/50 (0)	8/49 (16)[c]	31/49 (63)[c]
mineralization	0/50 (0)	29/48 (60)[c]	37/50 (74)[c]	0/50 (0)	49/49 (100)[c]	49/49 (100)[c]
cysts	0/50 (0)	0/48 (0)	1/50 (2)	0/50 (0)	3/49 (6)	3/49 (6)
Reproductive & Endocrine						
Pituitary -						
adenoma	7/48 (15)	18/49 (36)[b]	13/47 (28)	5/46 (11)	9/47 (19)	13/46 (28)
carcinoma	0/48 (0)	0/49 (0)	1/47 (2)	0/46 (0)	1/47 (2)	2/46 (4)
Thyroid -						
follicular cell tumors	2/45 (4)	0/44 (0)	0/44 (0)	0/49 (0)	2/49 (4)	1/50 (2)
c cell tumors	5/45 (11)	4/44 (9)	7/44 (16)	2/50 (4)	13/49 (26)[c]	7/50 (14)
hyperplasia	1/45 (2)	1/44 (2)	10/44 (23)[c]	5/50 (10)	3/49 (6)	3/50 (6)
Parathyroid -						
adenoma	1/35 (3)	2/35 (6)	0/33 (0)	1/38 (3)	2/42 (5)	1/42 (2)
Testes -						
interstitial cell tumor	46/49 (94)	44/46 (96)	40/50 (80)	48/49 (99)	48/50 (96)	43/47 (91)
Adrenal -						
cell change	18/50 (36)	13/50 (26)	15/50 (30)	10/50 (20)	12/50 (24)	19/47 (40)
carcinoma	0/50 (0)	0/50 (0)	0/50 (0)	1/50 (2)	0/50 (0)	0/47 (0)
adenoma	1/50 (2)	0/50 (0)	0/50 (0)	0/50 (0)	0/50 (0)	0/47 (0)
pheochromocytoma	4/50 (8)	4/50 (8)	8/50 (16)	1/50 (2)	0/50 (0)	8/47 (17)[b]
Lymphoreticular						
Thymus -						
thymoma	0/17 (0)	0/16 (0)	0/18 (0)	0/39 (0)	0/41 (0)	2/39 (5)
leukemia	14/50 (28)	5/50 (10)[b]	4/50 (8)[b]	12/50 (24)	7/50 (14)	11/50 (22)

[a] Number observed/Number examined (%).
[b] Different from control, $p < 0.05$.
[c] Different from control, $p < 0.01$.

TABLE 18. HISTOPATHOLOGIC LESIONS[a] IN FEMALE RATS HELD FOR POSTEXPOSURE OBSERVATION AFTER 90 DAYS OF CONTINUOUS INHALATION EXPOSURE TO JP-5

Tissue	Petroleum JP-5 Concentration (mg/m^3) 0	150	750	Shale JP-5 Concentration (mg/m^3) 0	150	750
Skin						
Mammary gland -						
hyperplasia/dilatation	3/36 (8)	16/43 (37)[b]	15/44 (3)[b]	11/46 (24)	23/45 (5)[b]	17/48 (35)
adenocarcinoma	0/36 (0)	2/43 (5)	3/44 (7)	1/46 (2)	1/45 (2)	0/48 (0)
cystadenocarcinoma	0/36 (0)	2/43 (5)	3/44 (7)	0/46 (0)	0/45 (0)	1/48 (2)
fibroadenoma	3/36 (8)	4/43 (9)	8/44 (18)	2/46 (4)	4/45 (9)	4/48 (8)
Musculoskeletal						
Bone -						
hyperostosis	3/43 (7)	10/45 (22)	9/47 (19)	7/47 (15)	20/49 (41)	18/50 (36)
Respiratory						
Nose - inflammation	2/44 (5)	0/46 (0)	4/44 (9)	0/49 (0)	3/50 (6)	1/48 (2)
Lung -						
adenoma	0/44 (0)	0/45 (0)	0/47 (0)	0/50 (0)	1/50 (2)	0/50 (0)
carcinoma	0/44 (0)	1/45 (2)	0/47 (0)	1/50 (2)	0/50 (0)	0/50 (0)
Liver						
Focal cell change	17/44 (37)	21/46 (48)	22/47 (50)	25/50 (50)	30/50 (60)	32/50 (64)
Neoplastic nodule	0/44 (0)	1/46 (2)	0/47 (0)	1/50 (2)	2/50 (4)	2/50 (4)
Urinary						
Kidney -						
tubualar degeneration	5/44 (11)	5/44 (11)	4/47 (9)	4/49 (8)	1/50 (2)	0/50 (0)
mineralization	0/44 (0)	0/44 (0)	1/47 (2)	0/49 (0)	0/50 (0)	1/50 (2)
cysts	0/44 (0)	0/44 (0)	0/47 (0)	0/49 (0)	1/50 (2)	1/50 (2)
Reproductive & Endocrine						
Pituitary -						
adenoma	16/42 (38)	22/46 (48)	22/44 (50)	10/45 (22)	23/47 (49)[b]	11/45 (24)
carcinoma	0/42 (0)	1/46 (2)	0/44 (0)	1/45 (2)	0/47 (0)	1/45 (2)
Thyroid -						
c cell tumors	3/37 (8)	3/40 (8)	6/44 (14)	5/49 (10)	7/49 (14)	4/49 (8)
hyperplasia	2/37 (5)	0/40 (0)	12/44 (27)[c]	6/49 (12)	7/49 (14)	2/49 (12)
Parathyroid -						
adenoma	0/25 (0)	0/32 (0)	0/35 (0)	0/36 (0)	2/41 (5)	0/40 (0)
Adrenal -						
cell change	9/44 (20)	5/45 (11)	9/47 (19)	18/49 (37)	13/50 (26)	19/50 (38)
carcinoma	0/44 (0)	0/45 (0)	0/47 (0)	1/49 (2)	0/50 (0)	0/50 (0)
adenoma	0/44 (0)	0/45 (0)	0/47 (0)	0/49 (0)	1/50 (2)	1/50 (2)
pheochromocytoma	3/44 (7)	1/45 (2)	1/47 (2)	0/49 (0)	1/50 (2)	3/50 (6)
Uterus -						
carcinoma	1/44 (2)	1/44 (2)	0/44 (0)	2/47 (4)	5/50 (10)	5/48 (10)
stormal polyps	11/44 (25)	14/44 (32)	8/44 (18)	4/47 (9)	5/50 (10)	7/48 (15)
Lymphoreticular						
Spleen -						
hemosiderosis	10/42 (24)	11/45 (24)	3/46 (7)[c]	10/50 (20)	29/49 (59)[b]	3/50 (6)[c]
leukemia	6/44 (14)	4/46 (9)	6/47 (13)	8/50 (16)	7/50 (14)	7/50 (14)

[a] Number observed/Number examined (%).
[b] Different from control, $p < 0.01$.
[c] Different from control, $p < 0.05$.

Unique to the female rats was the occurrence of bone hyperosteosis (osteosclerosis). This lesion was not recorded in any male rat and its etiology is believed to be related to increased levels of estrogen in aged females. Estrogen competes with parathyroid hormone for osteoclastic cell receptors and prevents parathyroid hormone from initiating bone resorption. Although this lesion occurred more frequently in JP-5 exposed females, there was no dose response relationship. Lesions noted in other organ systems of female rats were similar in nature to those previously discussed for male rats.

DISCUSSION

Male rat nephrotoxicity was a consistent effect produced by 90 days of continuous inhalation of Petroleum or Shale JP-5. Renal toxicity was apparent in virtually all exposed male rats immediately upon exposure termination, even at the lowest level of exposure tested, 150 mg/m^3. The renal tubular necrosis observed in male rats was considered to be an end product of severe hyaline degeneration. Hyaline droplets are normal components of the protein resorption process of the proximal convoluted tubule. Droplets are frequently accentuated in male rats where tubular cells must resorb and degrade increased levels of a highly filterable, and male rat unique protein, an α2u globulin (Alden et al., 1983). This globulin is produced in the liver of male rats only at puberty, and its low molecular weight facilitates rapid glomerular filtration. The biological fate of α2u globulin is unknown. Ostensibly, the inability of the kidney tubular cell to efficiently degrade resorbed α2u globulin is central to the pathogenesis of JP-5 induced nephrosis in male rats. Changes occurring in the kidneys subsequent to the 90-day exposure included increased deposits of mineralized debris in medullary tubules, papillary hyperplasia of the pelvis, and more severe chronic progressive nephropathy. Consistent with the pathologic changes observed in male rats exposed to 750 mg/m^3 JP-5 were increased kidney weight and serum creatinine and BUN levels. Body weights of male rats exposed to 750 mg/m^3 JP-5 were also consistently less than unexposed rats. Although structural changes were also observable at the 150 mg/m^3 level, kidney weights and blood kidney function indicators were generally not increased.

A similar type of male rat nephropathy has been observed after gavage with Petroleum or Shale JP-5 (Parker et al., 1981). Inhalation of hydrocarbon solvents has also been reported to produce tubular changes in male rats (Carpenter et al., 1975a, 1975b; Gaworski et al., 1984; Phillips and Egan, 1984a, 1984b). In the present study of JP-5 the renal toxicity was limited to

male rats and did not occur in female rats or female C57BL/6 mice. Easley et al. (1982) has reported renal toxicity consisting of cortical degeneration, possibly due to ischemia related dehydration, in C3Hf/Bd mice treated dermally with Petroleum or Shale JP-5, JP-8, or diesel fuel marine.

The vacuolization in the hepatocytes of mice and rats inhaling JP-5 for 90 days was probably an indication of fatty metamorphosis associated with excess lipid accumulation. Parker et al. (1981) found vacuolization in livers of rats gavaged with Petroleum or Shale JP-5 and also observed elevated liver function indices. In the present study, examination of rat serum chemistry parameters at exposure termination failed to suggest abnormal liver function. Since mouse blood was not examined, the effect of JP-5 induced fatty change on liver function in this species is unknown. At 19 months postexposure clinical liver function indices were normal. Additionally, at that time liver vacuolization was not a significant finding in rats and was noted with equal distribution in mice. These results suggest that the type and extent of liver damage produced by inhalation of JP-5 vapor at concentrations up to 750 mg/m^3 was mild and reversible.

Shale JP-5 vapors were apparently more irritating than Petroleum JP-5 to the nasal tissues. This was suggested by the nasal inflammation occurring in Shale JP-5 exposed rats but not in Petroleum JP-5 exposed rats. The nasal lesions were indistinguishable from those seen in early Mycoplasma pulmonis infection. However, microbiological cultures were not collected from the rats, so the presence of Mycoplasma pulmonis was not confirmed. Furthermore, it should be emphasized that histopathologic evaluation of other respiratory tissues failed to incriminate Mycoplasma pulmonis as a significant disease entity in any study group. The respiratory changes were reversible and significant structural alterations in the respiratory systems of JP-5 exposed animals were not evident at 19 months postexposure. Irritation or the solvent "defatting" characteristics of JP-5 may have been responsible for the increased skin ulceration noted in mice examined postexposure. However, it has been our experience that these lesions are common in C57BL/6 mice and trauma and biting associated with gang caging would not be ruled out as a specific cause of the skin lesions.

Exposure to either Petroleum or Shale JP-5 produced an apparent slight increase in endocrine tumors in rats, particularly tumors of the pituitary gland. However, these tumors are generally regarded as common aging neoplasms in Fischer 344 rats, and in the absence of any strong dose response relationship this increase is considered incidental. Most important was the

absence of any definite indication of increased tumor formation in any of the major organs of rats including the lungs, liver, and kidneys.

In conclusion, this comparative examination of the toxic effects of 90 days of continuous inhalation of JP-5 derived from Petroleum or Shale sources established no substantial difference between fuels. The major effect of exposure to JP-5 from either source was the production of histologic changes in male rat kidneys suggesting renal tubular nephropathy. The results of the study are consistent with other published reports of hydrocarbon fuel and solvent toxicity.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1986 559-006/10253

MILITARY SPECIFICATION

TURBINE FUEL, AVIATION, GRADES JP-4 AND JP-5

This amendment forms a part of Military Specification MIL-T-5624L, dated 18 May 1979, and is approved for use by all Departments and Agencies of the Department of Defense.

PAGE 2

2.2, American Society for Testing and Materials Standards

ASTM D 156: Delete title and substitute "Saybolt Color of Petroleum Products (Saybolt Chromometer Method), Test for".

ASTM D 240: Delete title and substitute "Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter".

PAGE 4

Table I:

Copper strip corrosion, 2 hrs at 100°C (212°F) max, under Fuel 11/:
Delete "lb" and substitute "1b".

Water reaction, Interface rating, max, under Fuel 11/:
Delete "lb" and substitute "1b".

Water separation index, modified, min, under Grade JP-5:
Delete "85" and substitute "14/".

PAGE 5

Table I:

Footnote 3/, line 3: Delete "760 mm pressure" and substitute "760 mm Hg pressure".

Footnote 9/, delete and substitute:

"9/ Test shall be performed in accordance with method 5327, 5330, or method 5340 of FED-STD-791."

Footnote 10/, delete and substitute:

"10/ The minimum water separation index, modified, rating for JP-4 shall be 85 with all additives except corrosion inhibitor and electrical conductivity additives present or 70 with all additives present except for the electrical conductivity additives.

Add:

"14/ The minimum water separation index, modified, rating for JP-5 shall be 85 with all additives except the corrosion inhibitor additive present or 70 with all additives present."

PAGE 6

3.3.1, delete and substitute:

"3.3.1 Antioxidants. Immediately after processing, an approved antioxidant shall be added to all JP-5 fuels, and to JP-4 fuels that contain blending stocks that have been hydrogen treated to prevent the formation of gums and peroxides after manufacture. JP-4 fuels that do not contain hydrogen treated blending stocks may have the antioxidant added at the option of the supplier. The concentration of antioxidant to be added shall be as follows:

a. For JP-5 and JP-4 (hydrogen treated): Not less than 6.0 pounds, nor more than 8.4 pounds of active ingredient per 1,000 barrels of fuel (17.2 to 24.0 mg/l).

b. For those JP-4 fuels not hydrogen treated, the supplier may (at his option) add not more than 8.4 pounds of active ingredient per 1,000 barrels of fuel (24.0 mg/l)."

PAGE 7

3.3.5, line 6: Delete "conductivity additive is approved" and substitute "conductivity additives are approved".

Add the following subparagraph to 3.3.5:

"b. Stadis 450 marketed by E. I. Dupont de Nemours & Co., Wilmington, DE."

PAGE 10

Concluding material, Custodian: Add "DLA-PS".

Add the attached omitted page 16.

Custodians:
Army - ME
Navy - AS
Air Force - 11
DLA - PS

Review activities:
Army - MI, AV
Air Force - 68

Preparing activity:
Air Force - 11

Project No. 9130-0101

10.6.3 If the heater tube has deposits which do not match the Color Standards, the following criteria shall be used:

10.6.3.1 If the deposit has peacock (rainbow) colors, rate this as code P (P for peacock). If some portion of the deposit does match the Color Standard, it shall be rated.

10.6.3.2 Deposits having abnormal colors (for example, blue or gray) shall have rating of code A (A for abnormal color) assigned.

10.6.3.3 When reporting the overall tube rating, record the rating of the maximum deposit which matches the Color Standards plus P or A if the tube contains deposits which do not match the Color Standards. If the tube contains only P or A deposits, just report the appropriate letter(s); do not try to assign a numerical rating to a P or A deposit. Examples of how the rating procedure is to be used are given below:

Example 1: The darkest deposits on the heater tube match color Standard 3. Also present are peacock colors. Thus, the overall tube rating to be reported is 3P.

Example 2: The heater tube has maximum deposits falling between Color Standards 2 and 3 and has no peacock or abnormal colors. The total tube rating is 2.

Example 3: The heater tube matches Color Standard 1 except for an abnormal deposit which does not match the ASTM Color Standards. The overall tube rating to be reported is 1A.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980 — 603-121/2944

MIL-T-5624L
18 May 1979
SUPERSEDING
MIL-T-5624K
1 April 1976

MILITARY SPECIFICATION

TURBINE FUEL, AVIATION, GRADES JP-4 and JP-5

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers two grades of aviation turbine fuel (see 6.1).

1.2 Classification. Aviation turbine fuel shall be of the following grades, as specified (see 6.2).

Grade	NATO Code No.	Description
JP-4	F-40	Wide cut, gasoline type
JP-5	F-44	High flashpoint, kerosene type

1.3 References. General references in other documents to turbine fuels in accordance with this specification with grade not specified, shall be interpreted to also include turbine fuels in accordance with MIL-T-83133.

2. APPLICABLE DOCUMENTS

2.1 Issues of documents. The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-I-25017	Inhibitor, Corrosion, Fuel Soluble
MIL-I-27686	Inhibitor, Icing, Fuel System
MIL-T-83133	Turbine Fuel, Aviation, Kerosene Type, Grade JP-8

STANDARDS

FEDERAL

FED-STD-791	Lubricants, Liquid Fuels, and Related Products; Methods of Testing

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASD/ENESS, Wright-Patterson AFB, OH 45433 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

MILITARY

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-290	Packaging, Packing and Marking of Petroleum and Related Products

Publications

Qualified Products List

QPL-25017	Inhibitor, Corrosion, Fuel Soluble

(Copies of specifications, standards, drawings, and publications required by contractors in connnection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

* 2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Tesing and Materials Standards

ASTM D 86	Distillation of Petroleum Products, Test For
ASTM D 93	Flash Point by Pensky-Martens Closed Tester
ASTM D 130	Detection of Copper Corrosion From Petroleum Products by the Copper Strip Tarnish Test, Method For
ASTM D 156	Saybolt Color of Petroleum Products (Saybolt Caronometer Method), Test for
ASTM D 240	Heat of Combustion of Liquid Hydrocarbon Fuels (General Bomb Method), Test for
ASTM D 270	Sampling Petroleum and Petroleum Products
ASTM D 323	Vapor Pressure of Petroleum Products (Reid Method)
ASTM D 381	Test for Existent Gum in Fuels by Jet Evaporation
ASTM D 445	Kinematic Viscosity of Transparent and Opaque Liquids (And the Calculation of Dynamic Viscosity)
ASTM D 484	Hydrocarbon Dry Cleaning Solvents (Doctor Test)
ASTM D 1018	Test for Hydrogen in Petroleum Fractions
ASTM D 1094	Test for Water Reaction of Aviation Fuels
ASTM D 1266	Test for Sulfur in Petroleum Products (Lamp Method)
ASTM D 1298	Test for Density, Specific Gravity, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D 1319	Test for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
ASTM D 1322	Test for Smoke Point of Aviation Turbine Fuels
ASTM D 1405	Estimation of Net Heat of Combustion of Aviation, Fuels, Method For
ASTM D 1655	Aviation Turbine Fuels, Standard Specification for
ASTM D 2276	Test for Particulate Contaminant in Aviation Turbine Fuels
ASTM D 2382	Test for Heat of Combustion of Hydrocarbon Fuels by Bomb Calorimeter (High-Precision Method)
ASTM D 2386	Test for Freezing Point of Aviation Fuels
ASTM D 2550	Test for Water Separation Characteristics of Aviation Turbine Fuels

ASTM D 2551	Test for Vapor Pressure of Petroleum Products (Micromethod)
ASTM D 2622	Test for Sulfur in Petroleum Products (X-Ray Spectrographic Method)
ASTM D 2624	Test for Electrical Conductivity of Aviation Turbine Fuels Containing a Static Dissipator Additive
ASTM D 2887	Test for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
ASTM D 3114	DC Electrical Conductivity of Hydrocarbon Fuels, Test for
ASTM D 3227	Mercaptan Sulfur in Gasoline, Kerosene, Aviation Turbine and Distillate Fuels (Potentiometric Method), Test for
ASTM D 3241	Test for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)
ASTM D 3242	Test for Total Acidity in Aviation Turbine Fuel
ASTM D 3338	Method for Estimation of Heat of Combustion of Aviation Fuels
ASTM D 3343	Method for Estimation of Hydrogen Content of Aviation Fuels
ASTM D 3701	Hydrogen Content of Aviation Turbine Fuels by Low Resolution Nuclear Magnetic Resonance Spectrometry
ASTM E 29	Recommended Practices for Indicating Which Places of Figures Are To Be Considered Significant in Specified Limiting Values.
ASTM E 380	Metric Practice Guide (A Guide to the Use of SI - The International System of Units)

(Copies of these standards may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19013.)

Department of Transportation

49 CFR 170-189	Department of Transportation Rules and Regulations for the Transportation of Explosives and Dangerous Articles
49 CFR 173-118	Exemption of Flammable Liquids
49 CFR 173-119	Flammable Liquids Not Specifically Provided For

(Copies of these documents may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.)

3. REQUIREMENTS

3.1 Materials. Except as otherwise specified herein, the fuel shall consist completely of hydrocarbon compounds.

* 3.2 Chemical and physical requirements. The chemical and physical requirements of the finished fuel shall conform to those listed in table I. Requirements contained herein are not subject to corrections for test tolerances. If multiple determinations are made, results falling within any specified repeatability and reproducibility tolerances may be averaged. For rounding off of significant figures, ASTM recommended practice E 29 (as referenced in ASTM D 381) shall apply to all tests required by this specification.

TABLE I. Chemical and physical requirements and test methods.

Requirements	Fuel 1/		Test Method ASTM Standards
	Grade JP-4	Grade JP-5	
Color, Saybolt	1/	1/	D 156
Total acid number, mg KOH/g, max	0.015	0.015	D 3242
Aromatics, vol percent, max	25.0	25.0	D 1319
Olefins, vol percent max	5.0	5.0	D 1319
Mercaptan sulfur, weight percent, max 2/	0.001	0.001	D 3227
Sulfur, total weight percent, max	0.40	0.40	D 1266 or D 2622
Distillation temperature, deg C, (D 2887 limits in parentheses)			D 86 3/ or D 2887
Initial boiling point	1/	1/	
10 percent recovered, max temp	1/	205 (185)	
20 percent recovered, max temp	145 (130)	1/	
50 percent recovered, max temp	190 (185)	1/	
90 percent recovered, max temp	245 (250)	1/	
End point, max temp	270 (320)	290 (320)	
Residue, vol percent, max (for D 86)	1.5	1.5	
Loss, vol percent, max (for D 86)	1.5	1.5	
Explosiveness percent, max	--	50	4/
Flash point, deg C (deg F), min	--	60 (140)	D 93
Density, kg/1, min (^{o}API, max) at 15^{o}C	0.751 (57.0)	0.788 (48.0)	D 1298
Density, kg/1, max (^{o}API, min) at 15^{o}C	0.802 (45.0)	0.845 (36.0)	D 1298
Vapor pressure, 37.8^{o}C (100^{o}F) kPa (psi), min	14 (2.0)	--	D 323 or D 2551
Vapor pressure, 37.8^{o}C (100^{o}F) kPa (psi), max	21 (3.0)	--	D 323 or D 2551
Freezing point, deg C (deg F), max	-58 (-72)	-46 (-51)	D 2386
Viscosity, at -20^{o}C, max centistokes	--	8.5 12/	D 445
Heating value, Aniline-gravity product, min, or Net heat of combustion, MJ/kg (Btu/lb) min	5,250	4,500	D 1405
	42.8 (18,400)	42.6 (18,300)	D 240, D 2382 or D 3338 5/
Hydrogen content, wt percent, min or	13.6	13.5	D 1018, D 3343, or D 3701 6/
Smoke point, mm, min	20.0	19.0	D 1322
Copper strip corrosion, 2 hr at 100^{o}C (212^{o}F) max	1b	1b	D 130
Thermal stability:			
Change in pressure drop, mm of Hg., max	25	25	D 3241 7/
Preheater deposit code, less than	3	3	
Existent gum, mg/100 ml, max	7.0	7.0	D 381
Particulate matter, mg/liter, max	1.0	1.0	D 2276 8/
Filtration time, minutes, max	15	--	8/
Water reaction			
Interface rating, max	1b	1b	D 1094
Water separation index, modififed, min	10/	85	D 2550
Fuel system icing inhibitor, vol percent min	0.10	0.10	9/
Fuel icing inhibitor, vol percent max	0.15	0.15	9/
Fuel electrical conductivity, pS/m, allowable range	200-600 13/		D 2624 or D 3114

TABLE I. Chemical and physical requirements and test methods. (Continued)

1/ To be reported - not limited.

2/ The mercaptan sulfur determination may be waived at the option of the inspector if the fuel is "doctor sweet" when tested in accordance with the doctor test of ASTM D 484.

3/ A condenser temperature of 32° to 40°F (0° to 4°C) shall be used for the distillation of grade JP-5. For JP-4, group 3 test conditions shall be used. Distillation shall not be corrected to 760 mm pressure.

4/ Test shall be performed in accordance with method 1151 FED-STD-791.

5/ ASTM D 3338, for calculating the heat of combustion, is only allowed for use with JP-4 fuel. When the fuel distillation test is also performed using ASTM D 2887, the average distillation temperature for use in ASTM D 3338 shall be calculated as follows:

$$V = \frac{10\% + 50\% + 95\%}{3}$$

6/ ASTM D 3343, for calculating the hydrogen content of the fuel, is only allowed for use with JP-4 fuel. When the fuel distillation test is also performed using ASTM D 2887, the average distillation temperature for use in D 3343 shall be calculated as follows:

$$V = \frac{10\% + 50\% + 95\%}{3}$$

7/ See 4.7.1.1 for ASTM D 3241 test conditions and test limits.

8/ A minimum sample size of one gallon shall be filtered. Filtration time will be determined in accordance with the procedure in Appendix A. The procedure in Appendix A may also be used for the determination of particulate matter as an alternate to ASTM D 2276.

9/ Test shall be performed with method 5327, 5330, or method 5340 of FED-STD 791.

10/ The minimum water separation index, modififed, rating for JP-4 shall be 85 with all additives except corrosion inhibitor and electrical conductivity additives present, or 70 with all additives present except for the electrical additives.

11/ Requirements and test methods for Grade JP-8 fuel are contained in MIL-T-83133.

12/ Until an ASTM therometer calibrated for the -20°C condition becomes available, this test may be conducted at -34.5°C (-30°F) with a maximum limit of 16.5 centistokes.

13/ The fuel electrical conductivity shall range between 200 and 600 picosiemens per meter when measured at the ambient fuel temperature or 85°F, whichever is lower.

3.3 Additives. The type and amount in each additive used shall be reported (see 6.2.1).

* 3.3.1 Antioxidants. Immediately after processing, an approved antioxidant shall be added to prevent the formation of gums and peroxides after manufacture. The concentration of antioxidant to be added shall be:

a. Not less than 6.0 pounds, nor more than 8.4 pounds of active ingredient per 1,000 barrels of fuel (17.2 to 24.0 mg/l) to all JP-5 fuels, and to JP-4 fuels that contain blending stocks that have been hydrogen treated.

b. At the option of the supplier, not more than 8.4 pounds of active ingredient per 1,000 barrels of fuel (24.0 mg/l) may be added to JP-4 fuels that do not contain any hydrogen treated blending stocks.

3.3.1.1 The following antioxidant formulations are approved:

a. 2,6-di-tert-butyl-4-methylphenol

b. 6-tert-butyl-2,4-dimethylphenol

c. 2,6-di-tert-butylphenol

d. 75 percent min-2,6-di-tert-butylphenol
25 percent max tert-butylphenols and tri-tert-butylphenols

e. 72 percent min 6-tert-butyl-2,4-dimethyphenol
28 percent max tert-butyl-methylphenols and tert-butyl-dimethylphenols

f. 55 percent min 6-tert-butyl-2,4-dimethylphenol
45 percent max mixture of tert-butylphenols and di-tert-butylphenols

g. 60 to 80 percent 2,6-dialkylphenols
20 to 40 percent mixture of 2,3,6-trialkylphenols and 2,4,6-trialkylphenols

h. 35 percent min 2,6-di-tert-butyl-4-methylphenol
65 percent max mixture of methyl-, ethyl-, and dimethyl-tert-butylphenols

i. 60 percent min 2,4-di-tert-butylphenol
40 percent max mixture of tert-butylphenols

j. 30 percent min mixture of 2,3,6-trimethylphenol and 2,4,6,-trimethylphenol
70 percent max mixture of dimethylphenols

k. 65 percent min mixture of 2,4,5-triisopropylphenol and 2,4,6,-triisopropylphenol
35 percent max mixture of other isopropylphenols and biphenols

l. 55 percent min butylated ethyl phenols
45 percent max butylated methyl and dimethyl phenols

3.3.2 Metal deactivator. A metal deactivator, N, N'-disalicylidene-1, 2 propanediamine or N,N'-disalicylidene-1, 2-cyclohexanediamine may be blended into the fuel in an amount not to exceed 2 pounds active ingredient per 1,000 barrels of fuel (22 mg/gal (US), 26 mg/gal (UK), or 5.8 mg/liter).

3.3.3 Corrosion inhibitor. A corrsoion inhibitor conforming to MIL-I-25017 shall be blended into the JP-4 and JP-5 fuel by the supplier. The amount added shall be equal to or greater than the minimum effective concentration and shall not exceed the maximum allowable concentration listed in the latest revision of QPL-25017. The supplier or transporting agency, or both, shall maintain and upon request shall make available to the Government evidence that the corrosion inhibitors used are equal in every respect to the qualified products listed in QPL-25017.

3.3.4 Fuel system icing inhibitor. The fuel system icing inhibitor is mandatory and shall conform to MIL-I-27686. The point of injection of the additive shall be determined by agreement between the purchase authority and the supplier.

* 3.3.5 Electrical conductivity additive. An electrical conductivity additive shall be added to JP-4 fuels in sufficient concentration to increase the conductivity of the fuel to within the range of 200 to 600 picosiemens per meter at the point of injection. The point of injection of the additive shall be determined by agreement between the purchasing authority and the supplier. The following electrical conductivity additive is approved.

a. ASA-3 marketed by the Shell Chemical Company, Houston, TX.

3.4 The workmanship. The finished fuel shall be visually free from undissolved water, sediment, or suspended matter and shall be clean and bright at the ambient temperature or at 21°C (70°F), whichever is higher.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other facilities suitable for performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Quality conformance inspection. For acceptance purposes, individual lots shall be examined as specified herein and subjected to tests for all requirements cited in section 3.

4.3 Inspection lot

4.3.1 Bulk lot. A bulk lot shall consist of an indefinite quantity of a homogeneous mixture of material offered for acceptance in a single isolated container.

4.3.2 Packaged lot. A packaged lot shall consist of an indefinite number of 55-gallon drums or smaller unit packages of identical size and shape offered for acceptance and filled from the isolated tank containing a homogeneous mixture of material.

4.4 Sampling

4.4.1 Sampling for verification of product quality. Each bulk or packaged lot of material shall be sampled for verification of product quality in accordance with ASTM D 270, except where individual test procedures contain specific sampling instructions.

4.4.2 Sampling for examination of filled containers for delivery. A random sample of filled containers shall be selected from each lot in accordance with MIL-STD-105 at inspection level II and acceptable quality level (AQL) of 2.5 percent defective. The samples shall be examined in accordance with 4.6.3.

4.5 Inspection. Inspection shall be performed in accordance with method 9601 of FED-STD-791.

4.6 Examinations

4.6.1 Examination of product. Samples selected in accordance with 4.4.1 shall be visually examined for compliance with 3.4.

4.6.2 Examination of empty containers. Prior to filling, each empty unit container shall be visually inspected for cleanliness and suitability.

4.6.3 Examination of filled containers. Samples taken as specified in 4.4.2 shall be examined for conformance to MIL-STD-290 with regard to fill, closure, sealing, leakage, packaging, packing, and markings. Any container having one or more defects under the required fill shall be rejected. If the number of defective or underfilled containers exceeds the acceptance number for appropriate plan of MIL-STD-105, the lot represented by the sample shall be rejected.

4.7 Test methods. Tests to determine conformance to chemical and physical requirements shall be conducted in accordance with FED-STD-791 or ASTM standards, using the applicable methods as listed in table I, except for the following.

4.7.1 Thermal stability

4.7.1.1 Thermal stability test. The thermal stability test shall be conducted using ASTM D 3241(JFTOT). The heater tube shall be rated visually (see Appendix B).

4.7.1.1.1 Test conitions

a. Heater tube temperature at maximum point: 260°C (500°F)

b. Fuel system pressure: 3.45 MPa (500 psig)

c. Fuel flow rate: 3.0 ml/minute

d. Test duration: 150 minutes.

4.7.1.1.2 Test results. The fuel sample is acceptable if all the following criteria are met:

a. The maximum visual rating of the heater tube deposits is less than a code 3.(appendix B, 10.6)

b. The visual rating of the heater tube shows neither peacock type deposit (code P) nor abnormal type deposits (code A)(appendix B, 10.6.3.1 and 10.6.3.2).

c. The maximum differential pressure across the test filter does not exceed 25 millimeters of mercury.

4.7.1.1.3 Reported data. The following data shall be reported.

a. Differential pressure in millimeters of mercury at 150 minutes, or time to differential pressure of 25 millimeters of mercury, whichever comes first.

b. Heater tube deposit code rating at the end of the test.

c. If a Mark 8A tube deposit rater is available, the maximum SPUN TDR rating shall be reported for information purposes.

4.8 Test report. Test data required by 4.7 shall be reported in accordance with ASTM D 1655, using the standard ASTM form entitled "Inspection Data on Aviation Turbine Fuels" or AFTO Form 476 (see 6.2.1).

5. PACKAGING

* 5.1 Packaging, packing, and marking. Packaging, packing, and marking shall be in accordance with MIL-STD-290. All fuel containers shall be marked with the actual flash point in degrees F of the fuel contained therein.

5.2 Transportation of fuels. The transportation of the JP-4 and JP-5 fuels shall be in accordance with the Department of Transportation Rules and Regulations listed in 2.2.

6. NOTES

6.1 Intended use. The fuels covered by this specification are intended for use in aircraft turbine, ramjet, and rocket engines.

* 6.2 Ordering data. Procurement document should specify:

a. Title, number, and date of this specification

b. Grade of fuel required (see 1.2)

c. Quantity required and size containers desired

d. Level of packaging and packing required (see 5.1).

e. Location and injection method for addition of fuel system icing inhibitor (both JP-4 and JP-5) and electrical conductivity additive (JP-4 only).

6.2.1 Contract data requirements. Data specified in 3.3 and 4.8 will be listed directly on a DD Form 1423 incorporated into the contract.

6.3 Precaution for mixing additives. To prevent any possible reaction between the concentrated forms of different additives (see 3.3), the fuel supplier is cautioned not to commingle additives prior to their addition to the fuels.

6.4 International agreements. Certain provisions of this specification are the subject of international standardization agreement ASCC 15/1 - STANAG 1135. When amendment, revision, or cancellation of this specification is proposed which affects or violates the international agreement concerned, the preparing activity shall take appropriate reconciliation action through international standardization channels including departmental standardization office, if required.

6.5 The margins of this specification are marked with an asterisk to indicate where changes (additions, modifications, corrections, deletions) from the previous issue were made. This was done as a convenience only, and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the last previous issue.

6.6 Units of measure have been converted to the International System of Units (Metric) in accordance with ASTM E 380.

6.7 Grade JP-8 fuel. Characteristics of JP-8 fuel (such as density, distillation temperature, etcetera) generally range between those of JP-4 and JP-5, being closer to JP-5. Materials and accessories suitable for use with both JP-4 and JP-5 are, in general, suitable for use with JP-8.

Custodian:
Army - MR
Navy - AS
Air Force - 11

Review activities:
Army - MI, AV
Air Force - 68

Preparing activity:
Air Force - 11

Project No. 9130-0093

APPENDIX A

METHOD FOR DETERMINATION OF JP-4 FILTRATION TIME & TOTAL SOLIDS (PARTICULATE)

10. Scope. This method describes a procedure for determining simultaneously the filterability characteristics and solids contamination of jet fuel. The purpose is to detect and prevent contaminants in jet fuel which can plug ground system as well as aircraft filtration equipment.

20. Summary of method. One gallon of jet fuel is filtered through a membrane filter in the laboratory. The time required to filter this volume is measured in minutes and solids content is determined gravimetrically.

30. Apparatus

a. Membrane filter: White, plain 47 mm diameter, nominal pore size 0.8 micron. The membrane must be approved by ASTM for use with method D 2276.

b. Filtration apparatus: Of the type shown in ASTM D2276, figure A3. It consists of a funnel and funnel base with a filter support such that a membrane filter can be securely locked or clamped between the sealing surfaces of the funnel and its base. The funnel and funnel base shall be of stainless steel or glass construction.

c. Insert ring: A 47-mm diameter stainless steel or paper flow reducer ring with dimensions to give filtering area of 4.8 cm^2. (Millipore Corporation Part No. XX10 047 07 or XX10 047 10.) To prevent possible static electricity problems, only the expendable paper flow reducer ring should be used with the glass funnel and funnel base apparatus.

d. Vacuum flask: A minimum of 4 liters.

e. Vacuum system: That develops a minimum of 20 inches of mercury vacuum.

f. Oven: Of the static type (without fan assisted circulation) controlling to 90 $\pm 5^{\circ}C$ (194 $\pm 9^{\circ}F$).

g. Forceps: Flat-bladed with unserrated nonpointed tips.

h. Solvent filtering dispenser: Containing a 1.2 micron maximum pore size filter in the delivery line.

i. Glass petri dish: Approximately 125 mm in diameter with removable cover.

j. Analytical balance: Single or double pan, the precision standard deviation of which must be 0.07 mg or better.

40. Preparation of apparatus and sample containers. All components of the filtration apparatus (except the vacuum flask), sample containers and their caps must be cleaned as described in A2.6.1.1 through A2.6.1.7 of ASTM D2276.

50. Sampling. Obtain a representative one gallon sample as directed in A2.7 of ASTM D2276. When sampling from a flowing stream is not possible, an all level sample or an average sample, in accordance with ASTM D-270 shall be permitted.

60. Test procedure

a. Membrane filters shall be removed from the package and placed in an oven for a minimum of 15 minutes at 90°C. After preheating, but prior to weighing, the membrane filters shall be stored in a desiccator.

b. Each membrane filter shall be weighed. A filter weighing in excess of 90 mg will not be used in the test.

c. The insert ring shall be centered on the filter base. The membrane filter shall be placed directly over the insert ring. The top funnel shall be locked into place.

d. Immediately prior to filtering the fuel, shake the sample to obtain a homogenous mix and assure that fuel temperature does not exceed 30°C (86°F). Clean the exterior top portion of the sample container to insure that no contaminants are introduced.

e. With the vacuum off, pour approximately 200 ml of fuel into the funnel.

f. Turn vacuum on and record starting time. Continue filtration of the one gallon sample, periodically shaking the sample container to maintain a homogenous mix. Record the vacuum in inches of mercury 1 minute after start and again immediately prior to completion of filtration. Throughout filtration, maintain a sufficient quantity of fuel in the funnel so that the membrane filter is always covered.

g. Report the filtration time in minutes expressed to the nearest whole number. If filtration of the one gallon is not completed within 30 minutes, the test will be stopped and the volume of fuel filtered will be measured. In these cases, results will be reported as 30+ minutes/volume of fuel filtered.

h. Report the vacuum in inches of mercury as determined from the average of the two readings taken in 60.f.

i. After recording the filtration time, shut off the vacuum and rinse the sample container with approximately 100 ml of filtered petroleum ether and dispense into the filtration funnel. Turn vacuum on and filter the 100 ml rinse. Turn vacuum off and wash the inside of the funnel with approxiamtely 50 ml of filtered petroleum ether. Turn vacuum on and filter. Repeat the funnel rinse with another 50 ml of petroleum ether but allow the rinse to soak the filter for approximately 30 seconds before turning the vacuum on to filter the rinse. With vacuum on, carefully remove the top funnel and rinse the periphery of the membrane filter by directing a gentle stream of petroleum ether from the solvent dispenser from the edge of the membrane toward the center, taking care not to wash contaminants off the filter. Maintain vacuum after final rinse for a few seconds to remove the excess petroleum ether from the filter.

j. Using forceps, carefully remove the membrane filter from the filter base and place in a clean Petri dish. Dry in an oven at 90°C (194°F) for 15 minutes with the cover on the Petri dish slightly ajar. Place dish in a desiccator and allow to cool for a minimum of 15 minutes. If more than one sample is processed, cooling time will have to be increased. Reweigh the filter.

k. Report the total solids content in mg/liter by using the following formula:

$$\frac{\text{Weight gain of filter in mgs}}{3.785} = \text{mg/liter}$$

l. Should the sample exceed the 30-minute filtration time and a portion of the fuel is not filtered, the solids content in mg/liter will be figured as follows: Determine the volume of fuel filtered by subtracting the ml of fuel remaining from 3785.

$$\frac{\text{Weight gain of filter in mgs}}{\text{ml of fuel filtered x } 0.001} = \text{mg/liter}$$

70. Test limits

a. Filtration time:

(1) Maximum allowable filtration time is 15 minutes

(2) The vacuum should exceed 20 inches of mercury throughout the test (i.e., the differential pressure across the filter should exceed 20 inches of mercury).

(3) The fuel temperature shall be between 18° amd 30°C (64° and 86°F).

b. Total solids: Maximum allowable particulate matter is 1.0 mg/liter.

80. NOTES:

80.1 If it is desired to determine the filtration time and not the total solids content, perform the test by omitting steps 60.i, 60.j, 60.k, and 60.l.

80.2 If it is desired to determine the total solids content and not the filtration time, use of the insert ring may be omitted. It is also permissible, but not required, to use a control filter for a specific analysis or a series of analyses. When this is accomplished, the procedures specified in A.2 of ASTM D 2276 apply.

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APPENDIX B

HEATER TUBE DEPOSIT RATING

10. Visual method

10.1 Snap the upper end of the heater tube into the clamp of the adapter for the heater tube.

10.2 Push the heater tube against the stop of the adapter tube.

10.3 Slide the adapter with the heater tube over the guide rod into the tuberator equipped with a magnifying glass assembly.

10.4 Insert the ASTM color standard into the tuberator.

10.5 Rotate the adapter and position the heater tube so that the side with the maximum deposit is visible.

10.6 Within 30 minutes after completion of the test, visually examine the heater tube in a tuberator. The entire portion of the test section between the bottom shoulder and the top shoulder of the heater tube test section shall be carefully examined using a magnifying glass in conjunction with the tuberator for any signs of discoloration, scratches, or other visually identified defects. When an area of the tube corresponds visually to an ASTM color standard, that color standard code number shall be recorded. If the area being rated has a color between two adjacent color standards, it shall be rated as the lighter (that is lower number) color standard. (NOTE: It is important that all light bulbs in the tuberator are functioning as a change in light intensity can shift the rating significantly.) (NOTE: The person rating the tube should have normal ability to distinguish between colors; i.e., he should not be color blind.)

10.6.1 In rating the heater tube, the darkest deposits govern and the code number representative of the darkest section, rather than the average deposit, shall be reported.

10.6.2 If a spot or streak is found on the heater tube, it shall be carefully examined under various lighting conditions using a magnifying glass to determine if it is a deposit, a scratch, or tube defect (note that the tube defects should have been found during the pretest inspection of the tube). If the spot or streak is determined to be a scratch or tube defect, it shall be disregarded. If the spot or streak is a deposit, it shall be rated against the ASTM color standards, if larger in area than about 0.004 square inch (0.025 sq cm); i.e., approximately 1/16 inch x 1/16 inch (1.5 mm x 1.5 mm) square or an equivalent area. However, a streak deposit shall be ignored if less than 1/32 inch (0.8 mm) wide, regardless of length. Note that the tube section is 1/8 inch (about 3 mm) in diameter; thus a 1/16 inch (1.5 mm) wide spot is half the diameter of the tube test section and 1/32 inch (0.8 mm) wide streak is one fourth the diameter of the tube test section.